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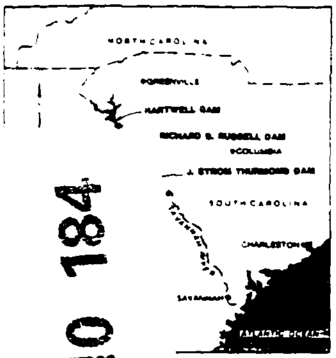

HYDRAULIC ANALYSES OF J. STROM THURMOND RESERVOIR HEADWATERS

by

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The US Army Engineer District, Savannah, is in the process of adding pumped/storage capability at the Richard B. Russell Project. The addition of four 75-MW pump/turbines will double the hydroelectric generation capacity while creating the capability to recharge the power pool in Russell Lake from the adjacent J. Strom Thurmond Lake. The completion of the Richard B. Russell powerhouse will result in a total capacity generation discharge of 60,000 cfs and pumping capacity of 24,800 cfs. The investigation reported herein examined the impacts of increasing the generation and pumpback flows of the project. Of particular concern was the interaction of flows with the downstream channel, which is constricted by sand deposits. The numerical model used in this study examined the velocity field and water-surface fluctuations associated with completed project flows in J. Strom Thurmond Lake. The results indicated a significant influence of the channel constriction on both the velocity field and water surface at capacity flow conditions for low tailwater pools. During periods of low tailwater pool, the duration of capacity pumpback would be limited. A channel realignment was proposed to improve the hydraulic conditions during project operation.

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PREFACE

The numerical model investigation of the Richard B. Russell project reported herein was conducted at the US Army Engineer Waterways Experiment Station (WES) at the request of the US Army Engineer District, Savannah.

The investigation was conducted during the period July 1987 to October 1988 in the Hydraulics Laboratory (HL), WES, under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL, and G. A. Pickering, Chief, Hydraulic Structures Division, and under the direct supervision of Dr. J. P. Holland, Chief of the Reservoir Water Quality Branch, Hydraulic Structures Division. This report was prepared by Mr. Michael L. Schneider, Reservoir Water Quality Branch, and was reviewed by Messrs. Holland, Pickering, and Mr. Mike Sydow of the Savannah District.

Acting Commander and Director of WES during preparation of this report was LTC Jack R. Stephen, EN. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
miles (US statute)	1.609344	kilometres

HYDRAULIC ANALYSES OF J. STROM THURMOND RESERVOIR HEADWATERS

PART I: INTRODUCTION

Background

1. The U.S. Army Engineer District, Savannah (SAS) manages water resources within the Savannah River Basin by the operation of three reservoir projects; Hartwell Dam, Richard B. Russell Dam (RBR), and J. Strom Thurmond Dam (JSTD), formerly Clarks Hill Dam (Figure 1). RBR Dam, situated between Hartwell and J. Strom Thurmond Reservoir (JSTR), is the most recently completed project. Prior to the construction of the RBR project, Hartwell Dam released directly into the Savannah River which emptied into JSTR at Trotter Shoals, some 29.9 miles* downstream. RBR was constructed in the headwaters of JSTR at Trotter Shoals. The project currently includes a hydroelectric power plant consisting of four vertical-axis, fixed-blade Francis turbines rated at 75 MW each with a net head of 145 ft at maximum conservation pool and a total discharge of 30,000 cfs.

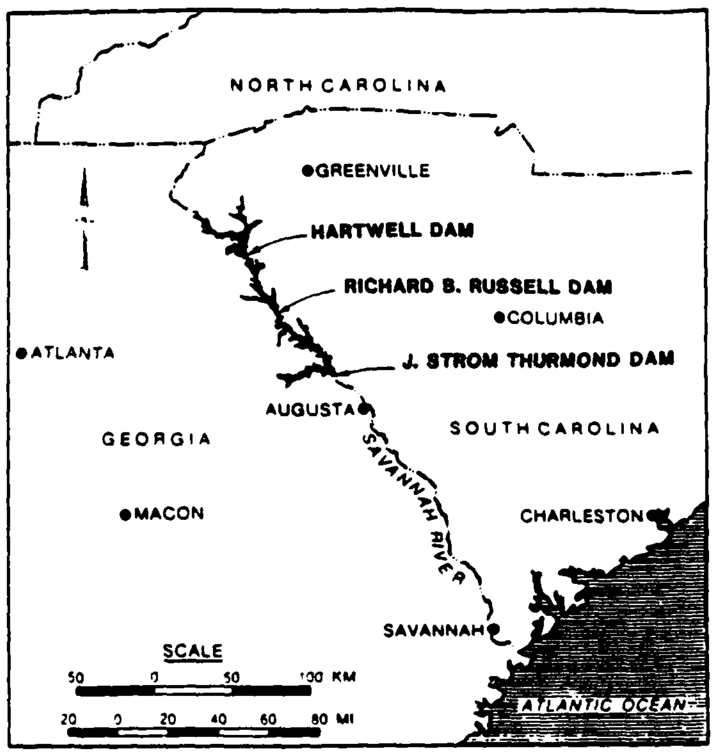

Figure 1. Location map

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* A table of factors for converting non-SI units of measurement to SI (metric) units of measurement is found on page 2.

SAS is currently pursuing plans to complete the powerhouse with an additional four 75 MW pump/turbine units with a rated generation capacity of 7,500 cfs each, yielding a maximum generation capacity of 60,000 cfs. Each of the four pump/turbines has a rated pumping capacity of 6,200 cfs for a combined pumping capacity of 24,800 cfs.

Project Description

2. The releases from the RBR project flow into JSTR located directly downstream. The RBR project consists of a powerhouse (625 ft wide) adjacent to the Georgia shore with a spillway section of about an equal width (600 ft) (Figure 2). The tailrace was constructed on a 1:5 slope for a distance of 175 ft downstream of the powerhouse and transitions into the natural headwaters of JSTR. The channel width of the afterbay region remains relatively constant within one-half mile of the dam with an average thalweg elevation of just under 300 ft NGVD* (Figure 3). The channel bed in this region is highly irregular because of material remaining from the construction phase of the project. Beyond the half mile mark the channel begins to widen accompanied by a rapid rise in the average channel bed elevation. Much of this region becomes dry as J. Strom Thurmond pool drops during low flow periods. The main channel, which is evident in this region, transitions into a sand flat at the mouth of the first major embayment in JSTR. This shallow sand bar extends to about 1.25 miles from the dam where the presence of a main channel reappears and the thalweg elevation returns to under 300 ft.

Purpose and Scope of Work

3. The bed material deposits in the study area act as a submerged weir relative to the hydraulic performance in the afterbay region of RBR Dam. In 1986, generation releases remained in the immediate afterbay region during low pool condition because of the existing channel constriction and low JSTR levels. The impact of this channel feature may have a significant influence on the operation of the completed powerhouse both in generation and pumpback modes. The potential for severe tailwater pool drawdown during pumpback operation may occur if upstream flow is constricted sufficiently in JSTR. The capacity of the pumps may be reduced significantly if tailwater drawdown is experienced, thereby increasing the time required to pump back a specified

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* All elevations and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

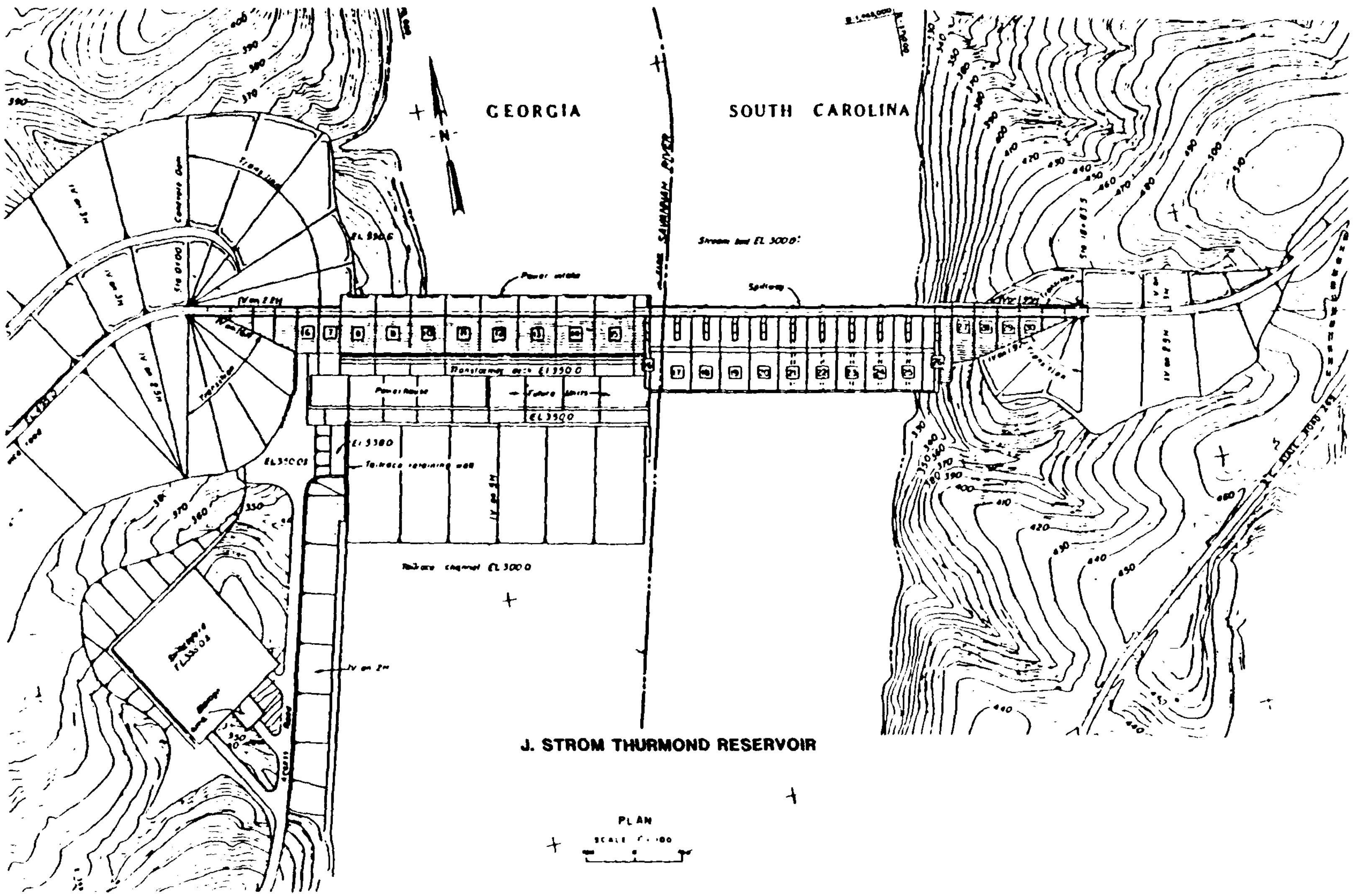

Figure 2. Richard B. Russell Dam overall site plan

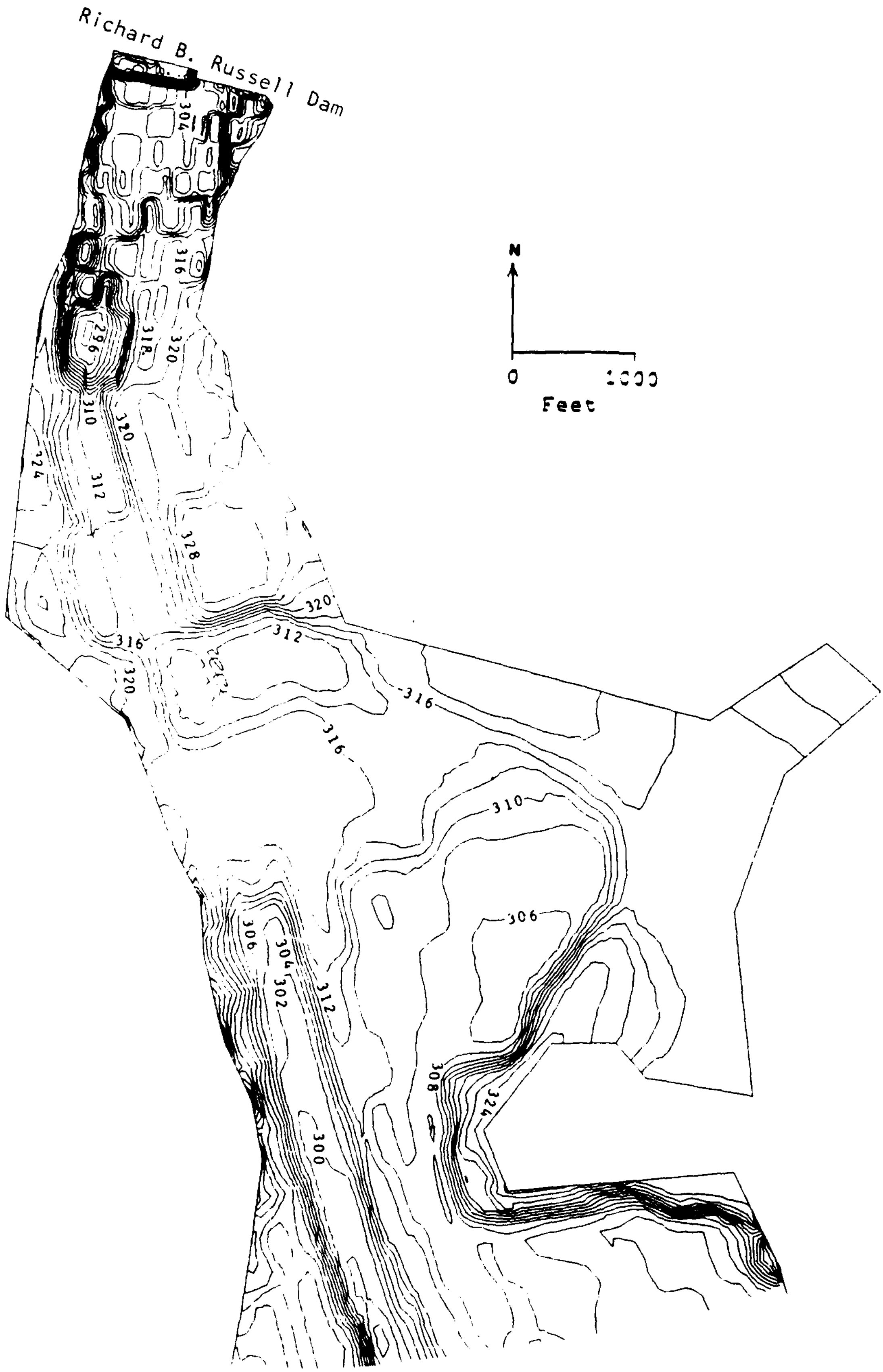

Figure 3. Contour map of Strom Thurmond Reservoir

volume of water. The potential for cavitation damage to the pump turbine also increases as tailwater stages drop. During generation, the shoaling region may result in backwater effects raising the tailwater pool that reduces the potential energy available for power production. Given that such hydraulic conditions would impair the operation of the completed powerhouse, SAS is prepared to dredge portions of the afterbay. The purpose of this study was to identify if adverse hydrodynamic conditions will develop upon the completion of the RBR powerhouse during capacity generation (60,000 cfs) and pumpback (24,800 cfs). Hydraulic conditions were studied using tailwater elevations ranging from normal pool (330 ft) to minimum pool (312 ft). If adverse hydraulic conditions are reflected in these results, a channel configuration was to be developed to minimize velocities and reduce potential impacts associated with plant operation. The SAS has concluded that channels with a 1:5 side slope will remain stable if dredging is to be considered in this region.

4. Any modification to the hydraulic conditions in the afterbay region must be consistent with the objective of minimizing the entrainment of fish during pumpback operation. At the initiation of this study, the behavioral response of JSTR fisheries to hydraulic conditions was in the developmental stages and could not be used as the basis for designing dredging alternatives. It is possible that future findings concerning the behavioral response of JSTR fisheries could provide additional guidance in the design of the dredged channel alignment to minimize the entrainment of fish. Many of the fish protection systems currently under consideration at the RBR project for the prevention of fish entrainment during pumpback operation are located in the project's tailrace area. The success of these systems is largely dependent upon the velocity of the water in the region in which the entrance to the systems are located. Bathymetric features in the afterbay region could influence both generation and pumpback flows significantly impacting the operation of the RBR project and the approach velocity to fish protection systems. Impacts of varying tailwater elevations on generation and pumpback flows in the tailrace region is reported in Schneider.* This earlier report was limited to investigating the velocity field within several hundred

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* M. L. Schneider. 1983 (Oct). "J. Strom Thurmond Reservoir Headwaters: Hydraulic Analyses," Memorandum for Record, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

feet of the powerhouse for steady-state flow conditions. The results reported herein will supplement prior hydraulic studies by identifying flow conditions resulting in tailrace stages previously simulated.

5. The approach taken for the study reported herein was to first assess the existing velocity fields associated with generation discharges through a field study. Representatives of the Waterways Experiment Station (WES), Hydraulics Laboratory, with help from the SAS and the WES Environmental Laboratory, conducted a field investigation of the velocity fields associated with generation discharges from RBR Dam. This field study concentrated on describing the far-field depth-averaged tailwater velocities.

6. The second phase of this study involved the use of field observations to develop a numerical model of the afterbay region of the RBR project for the prediction of hydraulic conditions at the completion of the project. Flow conditions during full conventional generation (60,000 cfs) and full pumpback (24,800 cfs) at tailwater elevations 330, 325, 320, 315, and 312 ft were modeled for the existing afterbay channel configuration. A one-dimensional steady-state model entitled HEC-2 was used to determine if adverse hydraulic conditions should be expected for the conditions described above. The required attributes of the modified channel to provide acceptable flow conditions can be analyzed quickly and inexpensively via this model.

PART II: FIELD STUDY INVESTIGATION

7. Depth-averaged steady-state velocities for a high- and low-flow event were monitored on four cross-sections in the afterbay regions of the RBR dam using a Price Current Meter. Four cross-sections were identified normal to the direction of flow for monitoring purposes. These transacts were located downstream of major changes in the channel cross section (Figure 4). Transect A was established at the buoy line approximately 750 ft downstream of the powerhouse. The succeeding three transects, B, C, and D, were located downstream of the dam approximately 2,250 ft, 4,250 ft, and 5,700 ft, respectively. Station markers were located at equal intervals across each transect to establish monitoring stations.

8. Constant hydropower releases were requested from SAS during the period of this study, which was conducted the week of 9 February 1987. A low-flow event consisting of releases of 8,900 cfs was scheduled for the first two days of this study, while a higher flow event of 12,000 cfs was scheduled for the final two days. The specific hydroturbines operated to obtain these flow conditions changed from day to day. The tailwater pool elevations during this study were near normal and ranged from 329.8 to 330.6 ft. The monitoring of far-field flow characteristics was delayed one hour after the initiation of power generation to allow steady state conditions to develop.

9. The monitoring equipment was rigged on a 24-ft Monark boat. A Price Current Meter with a digital display indicator for direct velocity readings and a current direction indicator compass for determination of the direction of flow were used to establish the flow field characteristics at a given depth. The current meter and compass were suspended from a boom mounted on the bow of the boat. A calibrated winch was used to raise and lower the current meter and compass to the desired depth. Records from the RBR power plant were used to establish tailwater stage characteristics during the study.

10. The flow patterns observed during this investigation indicated shifting flow distributions from transect to transect. Transect A indicated flow directed downstream along the Georgia bank and return flow directed toward the dam on the South Carolina bank (Figure 5). The predominant conveyance of flow shifted toward the South Carolina side of the channel at Transect B due to the remains of a cofferdam adjacent to the Georgia bank. The major component of flow moved back to the Georgia side of JSTR on the

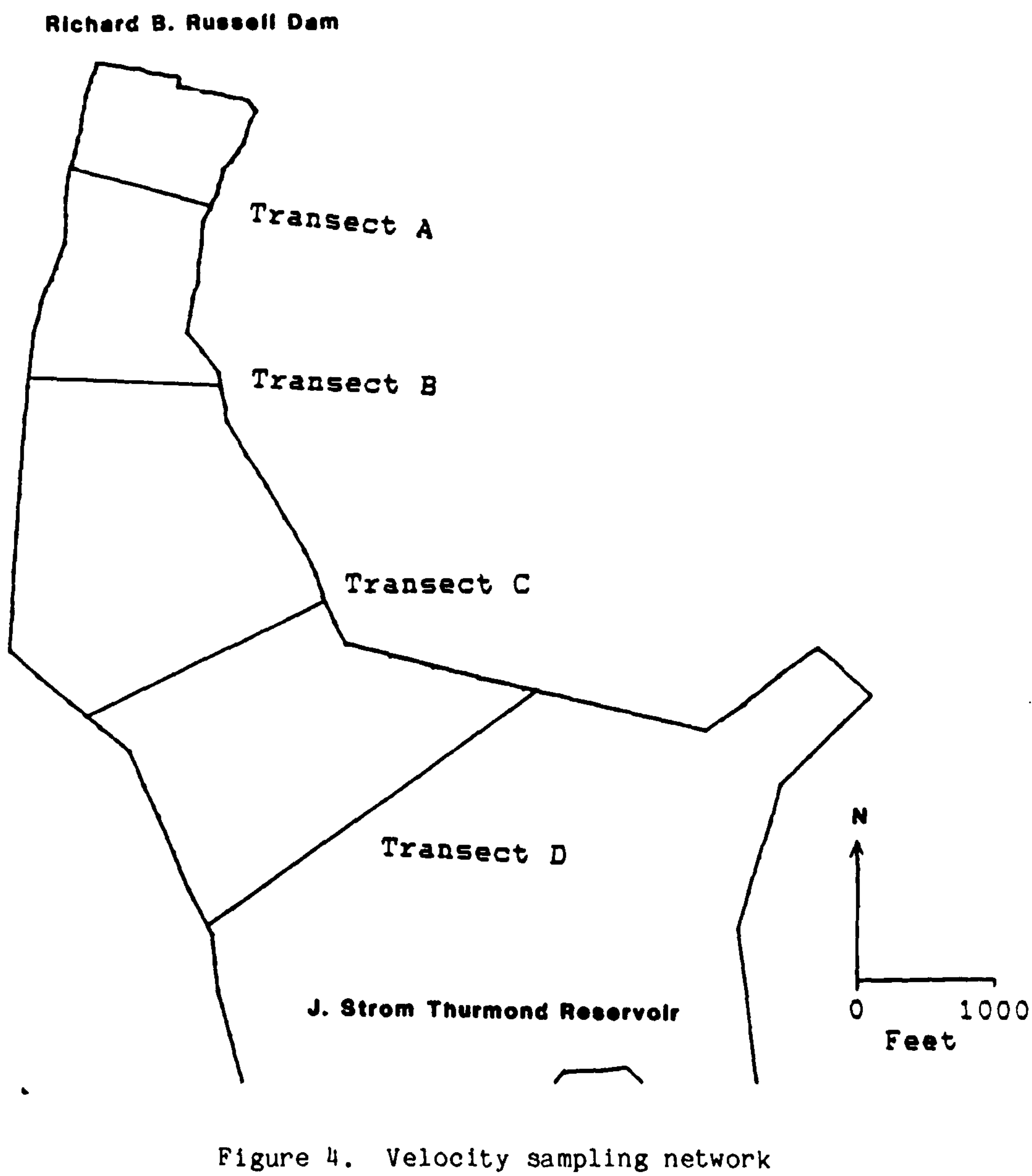


Figure 4. Velocity sampling network

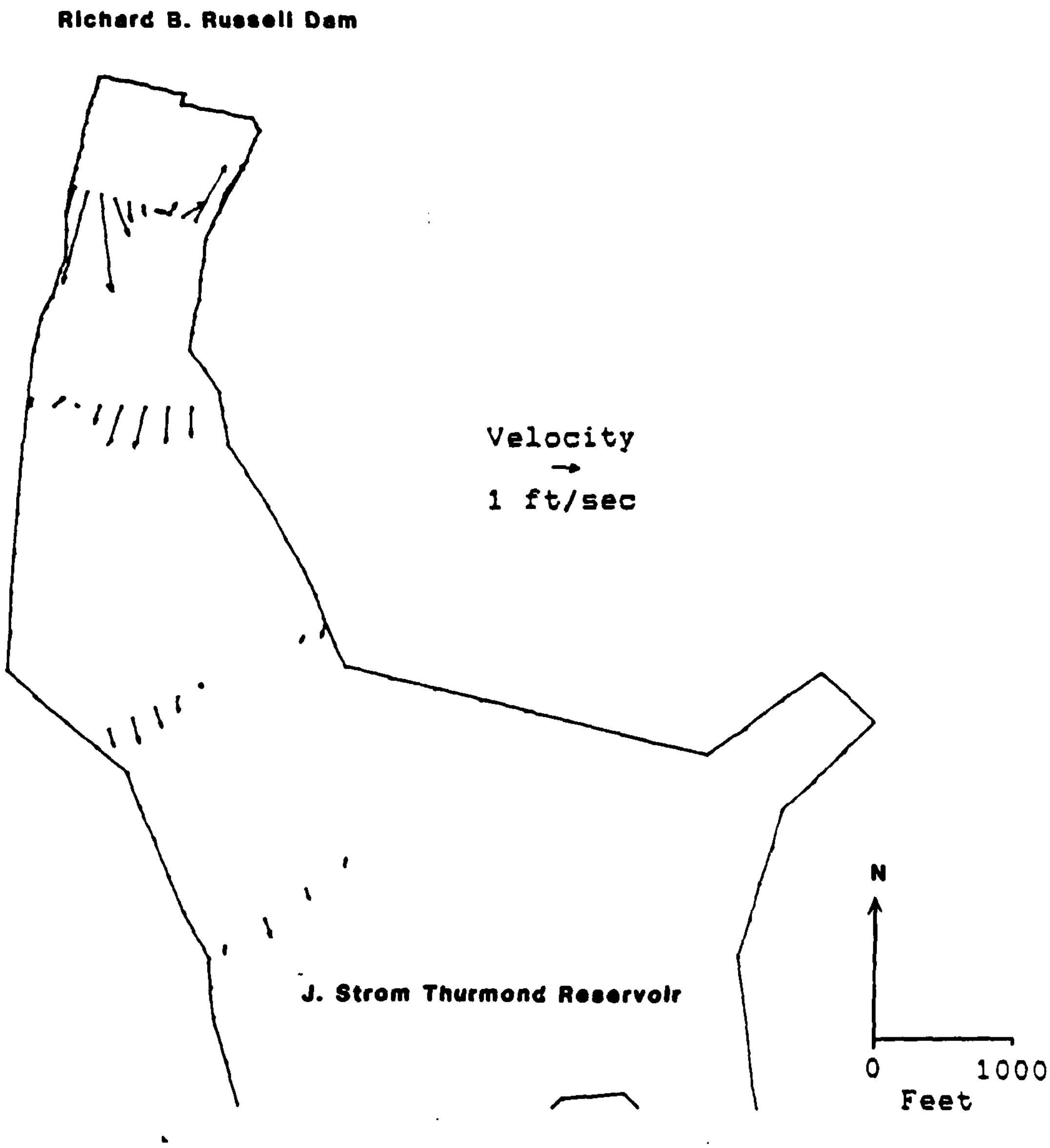


Figure 5. Velocity patterns for generation flow (8,025 cfs)

third velocity transect. This flow movement was caused by a shallow sand bar located predominantly in South Carolina. Velocities were significantly reduced on Transect D due to the abrupt expansion in the channel with the velocities skewed toward the Georgia bank. No measurable fluctuation in the tailwater stage was observed during these generation flows.

11. Historical records from the RBR powerplant have indicated the presence of increased tailwater stages during project releases (tailwater stage setup). The tailwater stage increase is directly proportional to the generation discharge and inversely proportional to the initial tailrace stage. Substantial tailrace stage fluctuations during project releases are more evident during lower-pool conditions in JSTR. Furthermore, higher project releases will result in greater tailrace setup, the degree of which is largely dependent on initial stage conditions. The power plant records of tailrace stages and project releases listed in Table 1 reflect these relationships. A maximum setup of about 5.6 ft was observed on 18 November 1986 with initial tailwater elevation of 316.65 ft during a 25,600-cfs release. The maximum setup over a month later on 25 December was only about 1.2 ft for an initial tailwater elevation of 322.4 during a 25,300 cfs release.

Table 1

Richard B. Russell Power Plant Records of Project Release and Tailwater Stage

	18 November 1986		25 December 1986	
Time (hours)	Flow (cfs)	Tailwater El (ft)	Flow (cfs)	Tailwater El (ft)
1700	0	316.80	0	322.46
1800	0	316.80	6,390	322.66
1900	22,130	321.70	23,150	323.60
2000	25,630	322.40	25,300	323.65
2100	18,720	321.10	10,470	322.48
2200	3,960	317.23	960	322.20
2300	3,960	317.23	0	322.20
2400	0	316.65	0	322.20

PART III: NUMERICAL MODEL CALIBRATION

Numerical Model

12. The HEC-2 computer program (CE 1982) was developed for calculating the water surface profiles for steady, gradually-varied flow in channels. The program solves the one-dimensional energy equation using the Standard Step Method subject to frictional resistance as determined by Manning's equation. The program can handle both supercritical and subcritical flow provided that the flow is one dimensional and invariant in time. This model was used to study the influence of channel features in the headwater regions of JSTR during capacity pumpback and generation on water surface profiles subject to various tailwater pool conditions. It was anticipated that the channel features would become increasingly influential on the resultant water surface profiles as tailwater conditions approached minimum pool (312 ft).

13. The data required to simulate flow conditions with the HEC-2 program include channel geometry and energy loss coefficients. The channel geometry was obtained from hydrographic surveys conducted by SAS in the headwater regions of JSTR during 1986 and 1987. The 1987 survey included cross-sectional information from the project to approximately one mile downstream. The transects were spaced on about 250-ft intervals for the first one-half mile downstream from the project as shown in Figure 6 (L300-L5000). Channel geometry beyond one mile from the project was taken from the 1986 survey. The 1986 survey extended the description of JSTR an additional 1.4 miles with transects spaced approximately on 500-ft intervals. The coverage of cross-sections L5500 through L8000 were extended to the South Carolina bank by assuming a linear elevation transition from a known transect elevation to an assumed bank elevation of 315 ft. Aerial photographs during low tailwater pool conditions revealed little variation in the inundated extent of JSTR in this region. A total of 25 transects were used to describe the bathymetric features in the headwaters of JSTR (Appendix A1-A25).

14. The bathymetric features undergo significant change within the study area. The hydrographic survey data indicate that the location of major flow constriction is dependent upon the tailwater pool level. The channel width (1150 ft) and thalweg elevation (300 ft) remain relatively constant from the project (L300) though Transect L2000 (Table 2). The minimum elevation on Transect L300 reflects the excavation of the tailrace. The bathymetric

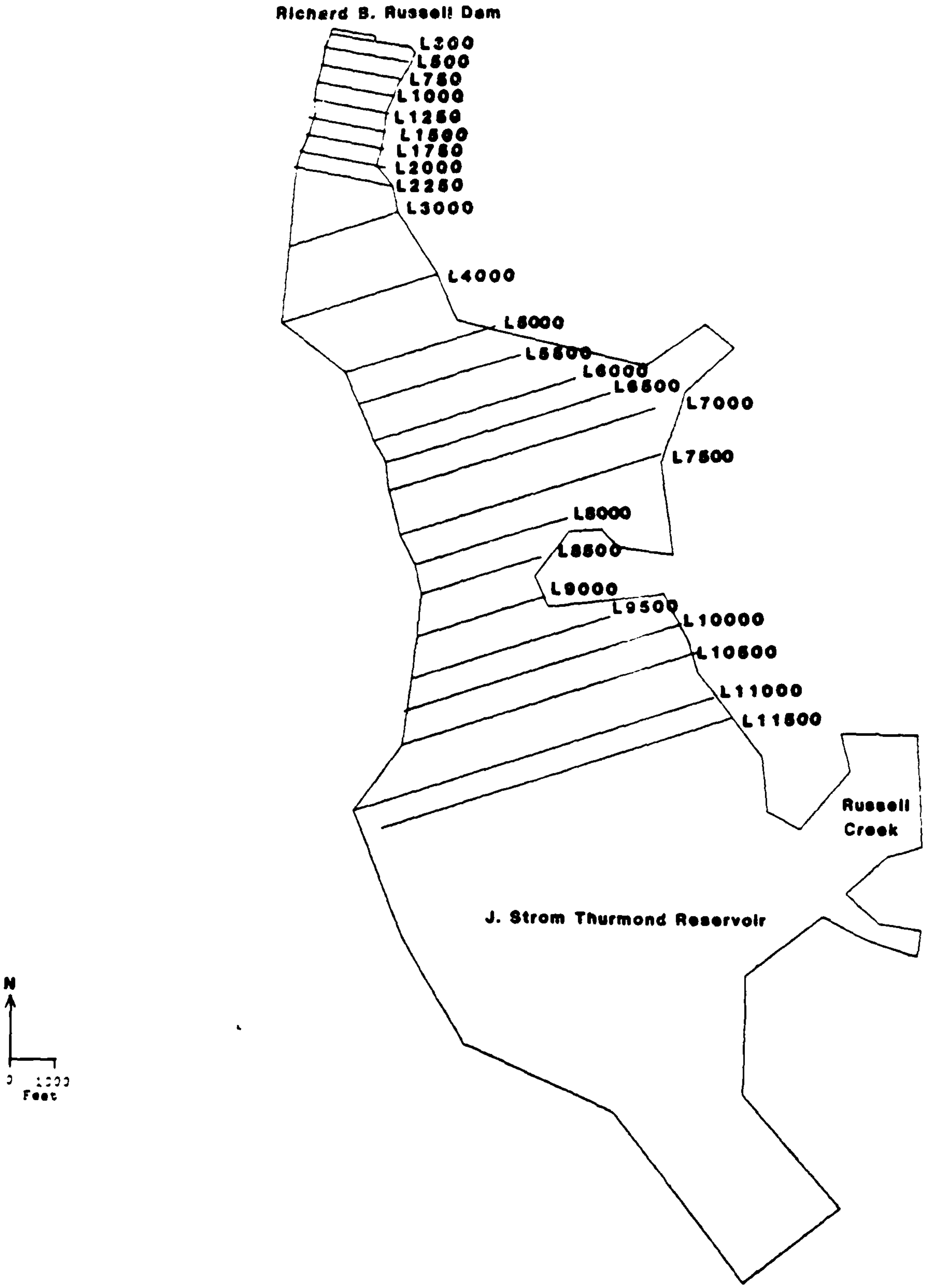


Figure 6. Hydrographic survey transects

Table 2

J. Strom Thurmond Reservoir Headwater Channel Features

Station No.	Distance From Dam (Miles)	Thalweg Elevation (ft)	Normal Pool Width (ft)	Hydraulic Depth (ft)	Area 312 Pool (Sq. ft)	Area 315 Pool (Sq. ft)	Area 320 Pool (Sq. ft)	Area 325 Pool (Sq. ft)	Area 330 Pool (Sq. ft)
L300	0.00	270	1171	40.6	26,637.7	30.072.0	35,885.0	41,739.8	47,594.6
L500	0.04	298	1229	23.7	8,752.4	11.626.3	16,938.5	22,975.0	29,118.3
L750	0.09	300	1160	21.6	6,002.3	8.790.0	13,719.2	19,200.9	25,000.7
L1000	0.13	299	1138	26.6	10,249.8	13.445.0	18,949.0	24,529.1	30,215.0
L1250	0.18	301	1108	21.3	4,348.7	7.424.0	12,675.2	18,079.6	23,617.5
L1500	0.23	300	1134	15.5	1,636.8	2.974.9	6,769.0	11,971.1	17,593.8
L1750	0.28	296	1137	18.4	2,943.1	4.657.3	9,722.2	15,238.5	20,894.6
L2000	0.33	299	1260	15.4	1,297.2	2.860.5	7,344.5	13,151.2	19,413.8
L2250	0.37	294	1433	15.8	5,139.6	6.377.1	9,898.9	15,602.8	22,639.9
L3000	0.52	310	1654	10.1	262.1	1.206.0	3,502.4	8,481.1	16,714.3
L4000	0.71	312	2340	7.6	6.8	560.9	3,452.8	8,802.4	17,747.9
L5000	0.93	311	2274	16.1	555.0	4,892.4	14,019.3	25,332.5	36,698.6
L5500	1.03	314	2442	14.2	0.0	585.2	10,208.0	22,420.1	34,632.3
L6000	1.16	314	2159	20.2	0.0	372.4	12,995.5	28,292.9	43,590.3
L6500	1.24	308	3391	16.4	1,821.2	6,601.7	21,619.0	38,502.5	55,453.7
L7000	1.33	303	4013	19.9	10,719.9	20,213.1	39,714.2	59,763.9	79,830.2
L7500	1.45	301	4018	20.2	12,985.9	23,209.1	42,462.6	61,841.8	81,346.8
L8000	1.62	300	2294	22.2	10,301.9	16,784.2	28,092.6	39,469.0	50,902.5
L8500	1.72	299	1800	20.6	8,332.2	12,428.8	19,713.0	27,998.3	36,999.2
L9000	1.84	298	1890	20.4	7,614.1	11,596.9	19,897.3	29,161.6	38,605.7
L9500	1.96	297	2997	22.8	15,812.3	23,668.2	38,233.3	53,219.9	68,206.5
L10000	2.06	294	4200	22.5	21,505.5	32,511.9	52,806.4	73,714.5	94,695.4
L10500	2.14	295	4500	23.1	24,611.0	37,412.1	59,337.9	81,586.8	104,073.6
L11000	2.31	293	5438	21.9	25,290.8	39,738.7	65,515.3	92,068.5	119,198.8
L11500	2.39	295	5294	23.3	28,459.2	43,968.0	70,214.3	96,660.6	123,127.4

features in the first one-third mile downstream from the project are highly irregular, indicating the bed material may be composed of larger sized particles that cannot be transported farther downstream by project releases. A considerable amount of material appears to have accumulated on Transect L1500 as indicated by the significant reduction in cross-sectional area at normal pool conditions as compared to adjacent transects. The presence of a deep channel also becomes apparent at Transect L1500. This channel proceeds downstream adjacent to the Georgia bank for the next 1,000 ft.

15. Beyond transect L2250 the average channel width and elevation increases significantly, thereby reducing the available conveyance area during normal pool conditions. The channel bed becomes much more continuous throughout this region indicating finer bed material, which can be transported during certain periods of project operation. The widening of the channel may have prompted the deposition of sediment in this region prior to and during the construction of the RBR Dam much like the formation of a delta at a river mouth. Significant sediment deposition in this region has ceased since the establishment of Russell Lake. The narrow, deep channel on Transect L2250 transitions into a relatively broad shallow cross section of uniform elevation on Transect L5500. The largest accumulation of material occurs between Transects L3000 and L4000 where the hydraulic depths are only 10.1 ft and 7.6 ft, respectively at normal pool conditions.

16. A main channel adjacent to the Georgia shore reappears approximately 1.25 miles downstream from the project (L6500). The thalweg decreases linearly throughout the remainder of the study area. A major contraction occurs at Transect L8500 followed by an expansion into the second major embayment in JSTR. The navigation channel migrates to the South Carolina bank south of the contraction. The study area ends just north of the Russell Creek tributary.

Numerical Model Verification

17. The Manning's "n" coefficient is generally determined by reproducing a known hydraulic grade line throughout the study region. Stage information within the study reach is limited to the powerhouse records of hourly tailwater pool during conventional generation. During the field study investigation, the steady generation of about 12,000 cfs at normal pool conditions resulted in no significant fluctuation in the tailwater pool. The determination of the frictional resistance in the form of the Manning's "n"

was therefore based upon modeling events observed during the 1986 calendar year. A total of 19 separate flow events with various initial tailwater stages and generation flow rates were modeled. The flow characteristics and date of each event are shown in Figure 7. The frictional resistance in the channel was adjusted by comparing the observed tailwater setup to the calculated tailwater setup. The selected Manning's "n" value of about 0.03 was chosen as providing the best fit to the observed data for existing channel conditions. The validity of the chosen frictional resistance for a wide range of flow conditions is illustrated by the plot of observed and calculated tailwater setup in Figure 8. The contraction and expansion loss coefficients used in this study were 0.1 and 0.3, respectively.

18. Results from the field study revealed regions of recirculation during generation flows. This flow feature was introduced into the one-dimensional simulations by defining an effective flow area on cross-sections near the dam. These flow characteristics were not expected to be present during capacity pumpback flow conditions.

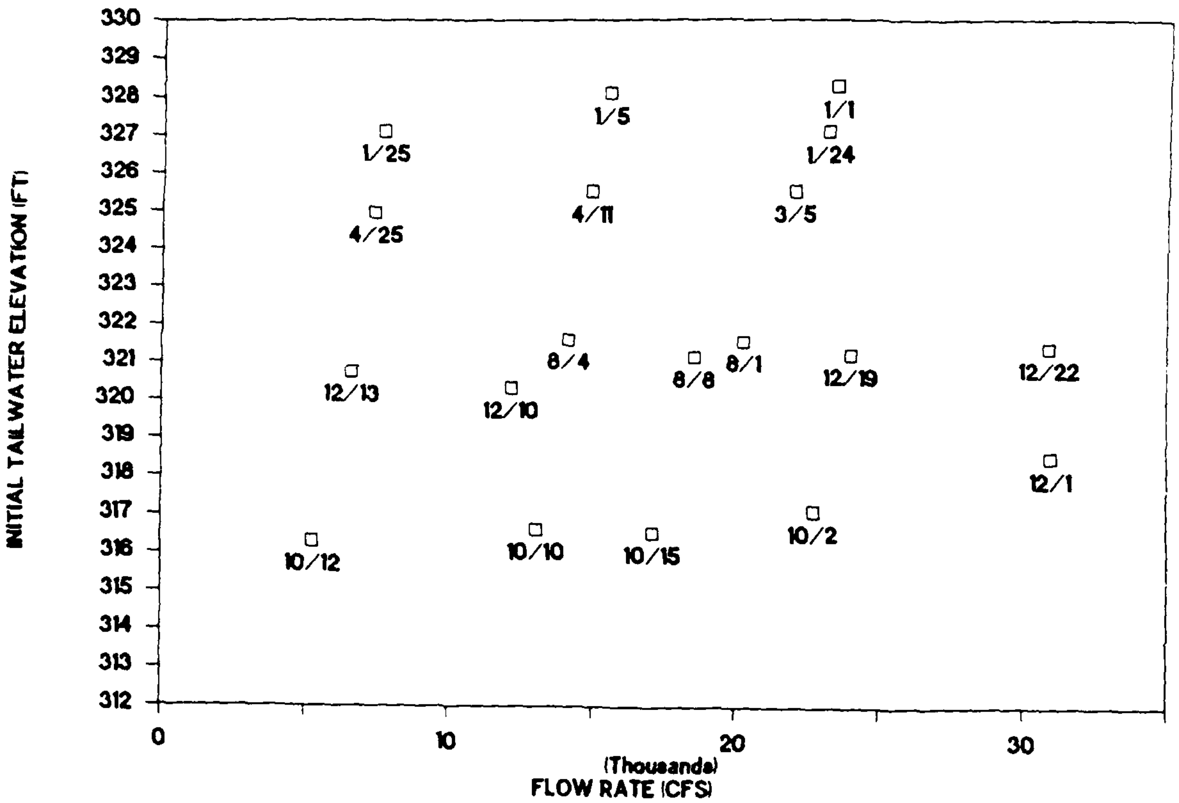


Figure 7. Flow conditions for model verification

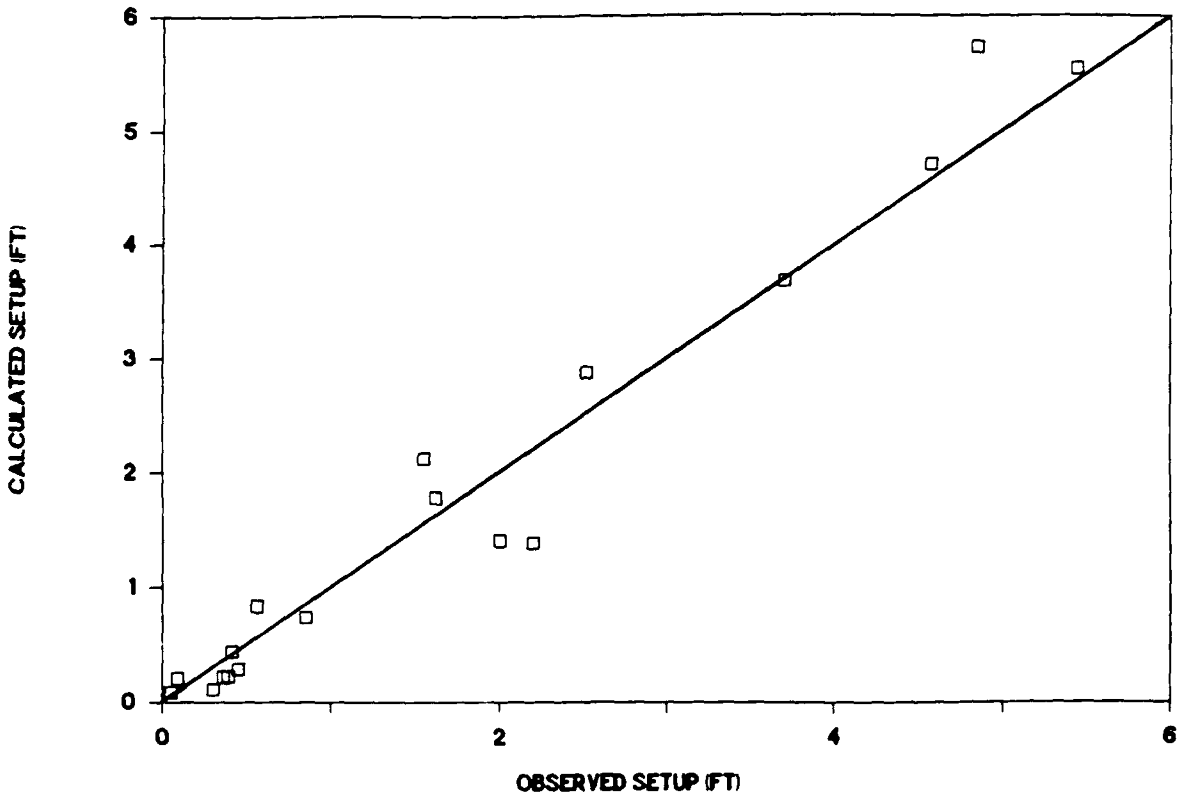


Figure 8. Observed versus calculated tailwater setup

PART IV: NUMERICAL MODEL SIMULATION OF EXISTING CHANNEL

19. Capacity generation of 60,000 cfs was simulated using the HEC-2 model assuming JSTR pool elevations of 330, 325, 320, 315, and 312 ft. The model determined the resultant tailrace pool level which would provide conveyance of this flow rate during steady-state capacity generation conditions. Since the hydroelectric generation at RBR is scheduled to meet peak power demands, steady-state flow conditions resulting from generation flows throughout the study area may not be a frequent occurrence. Flow conditions within one mile of the dam should, however approach steady-state conditions after several hours of capacity generation based upon time of travel estimates for existing conditions. These simulations provide an opportunity to evaluate the backwater effects to be expected during certain flow conditions. Any pooling of water in the tailrace region would reduce the effective head available for hydroelectric generation. The water-surface profiles for these five simulations are illustrated in Figure 9.

20. The backwater effects for capacity generation became significant when JSTR levels dropped below elevation 325 ft. When reservoir levels were above elevation 325 ft, the existing reservoir channel could convey the 60,000-cfs release without significantly influencing the water surface. As the reservoir level dropped below elevation 325 ft, the tailrace pool elevation remained almost constant due to the downstream shift in flow control. The most significant gradient in the water-surface slope occurred at Transect L4000 for pool elevations below 325 ft. This shallow region acted as a weir causing water to accumulate in the tailrace region.

21. The average channel velocities during capacity generation can be expected to exceed 2 fps throughout much of the study area for all pool conditions modeled. For normal pool conditions, the average cross sectional velocities were greater than 2 fps within a mile of the RBR Dam with a maximum velocity of 3.5 fps on Transect L4000. As the JSTR level dropped, the corresponding velocities increase significantly. The maximum velocity almost doubled on Transect L4000 as the pool level in JSTR was dropped from 330 ft to elevation 325 ft. When the reservoir level dropped below 325 ft, critical flow conditions developed on Transect L4000 in order to convey the capacity generation flow rate of 60,000 cfs. It is highly unlikely that these high

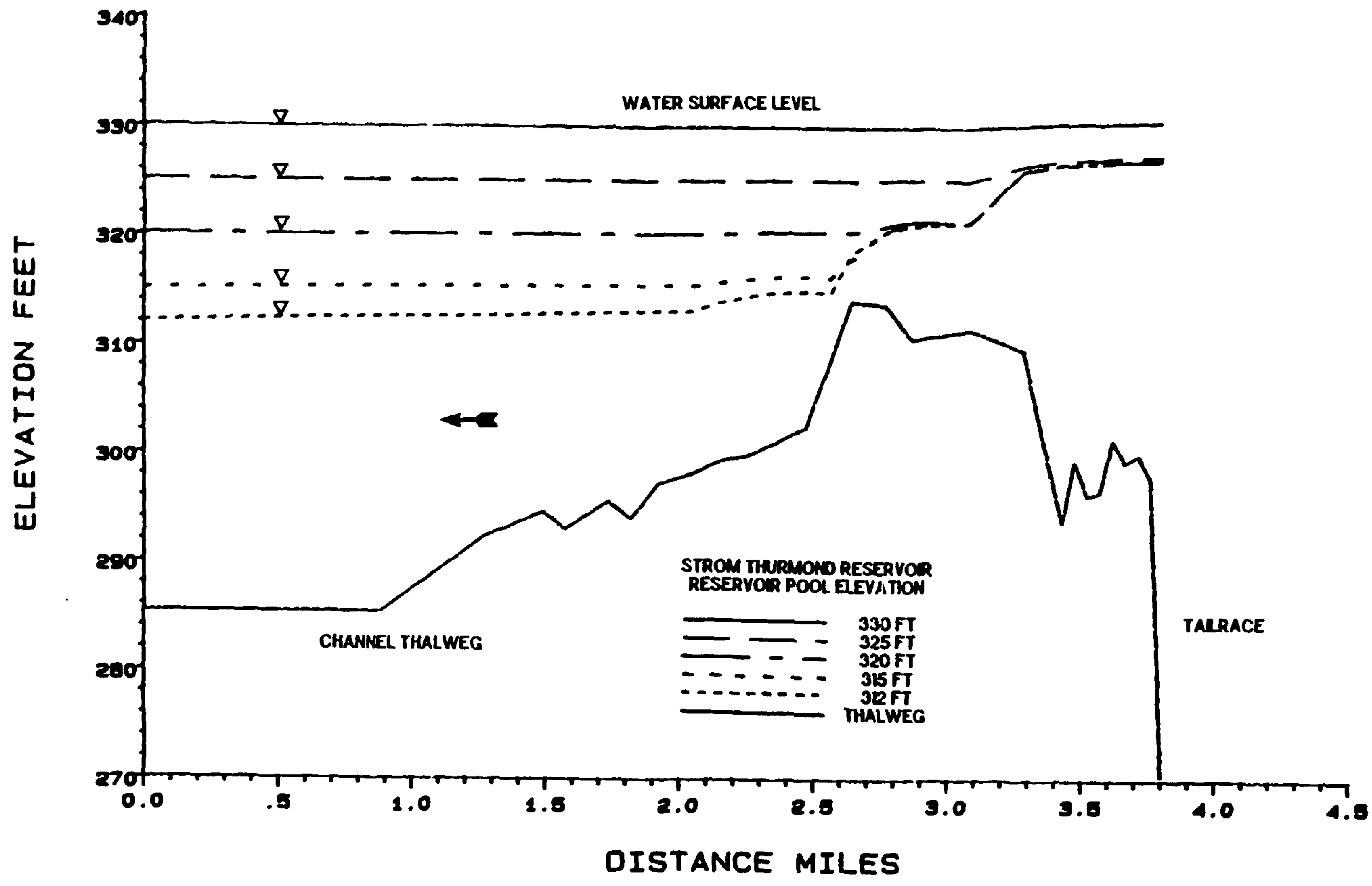


Figure 9. Water-surface profiles for Strom Thurmcnd Reservoir capacity generation, Q = 60,000 cfs (n - 0.03)

velocity conditions would develop in the headwater regions of JSTR without significant local scour occurring. Degradation of the channel bed in this region would reduce channel velocities until a stable channel alignment has been reached. Geological borings of the reservoir bed have revealed an erosion resistant bed rock located well beneath the thalweg of the existing channel. It is possible that the natural degradation expected in the headwaters of JSTR, as a result of the change in the flow regime, could significantly increase the channel capacity thereby reducing or eliminating the need for dredging. Estimation of the sediment transport throughout the study area was beyond the scope of this study. The longitudinal velocity profiles for capacity generation for modeled conditions are shown in Figure 10. These velocities represent average cross-sectional properties.

22. Capacity pumpback of 24,800 cfs was simulated using HEC-2 model assuming tailrace pool elevations of 330, 325, 320, 315, and 312 ft. The JSTR level was determined which would provide conveyance of this flow rate to the pumping station at the Dam. These simulations provide an opportunity to evaluate the degree of drawdown to be expected during certain flow conditions. This drawdown will cause a greater use of resources to pump back a given volume of water.

23. The capacity pumpback simulations for pool elevations 330, 325, and 320 ft resulted in only minor effects to the tailrace stages. The effects of draw down in the tailrace area became significant only when JSTR levels dropped below elevation 320 ft. Under these flow conditions water was pumped out of the tailrace region faster than it could be replaced by water from JSTR resulting in tailrace drawdown. Under some conditions, the tailrace pool continued to drop until it became unfeasible to operate in a pumping mode. The water-surface profiles for these five simulations are illustrated in Figure 11.

24. The average channel velocities within a mile of the dam from capacity pumpback exceed 2 fps for JSTR pool levels below elevation 325 ft. The maximum velocity of 3 fps occurred on Transect L4000 for capacity pumpback at pool elevation 325 ft. The average channel velocities exceeded 2 fps throughout the region bounded by Transects L1500 through L5000. The maximum velocity more than doubled when the tailrace stage was lowered to elevation 320 ft. Critical flow conditions developed on both Transects L1750 and L4000 for JSTR pool conditions of 315 ft and 312 ft. Continuous draw down of the

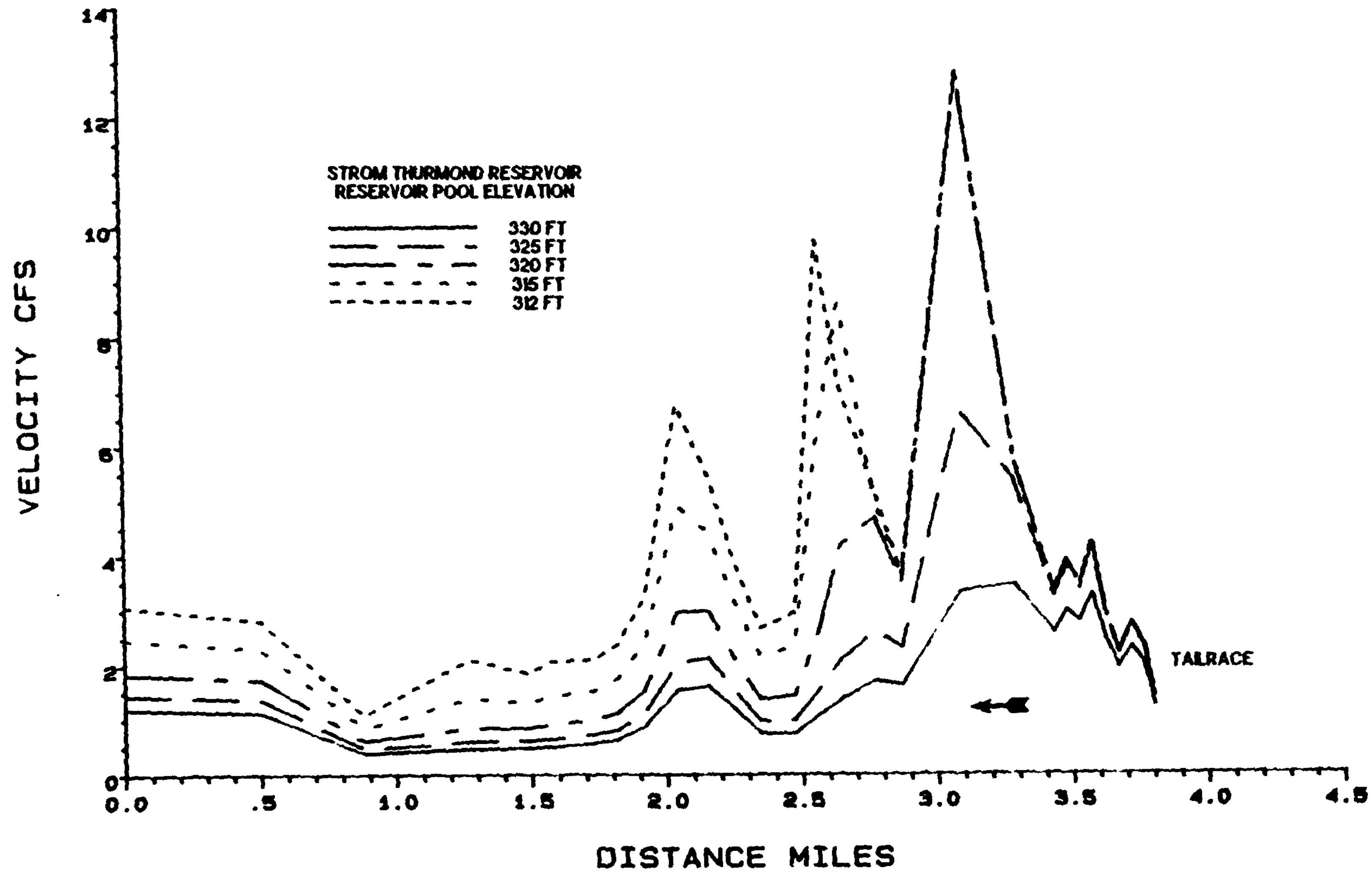


Figure 10. Velocity profiles for Strom Thurmond Reservoir capacity generation, Q = 60,000 cfs (n = 0.03)

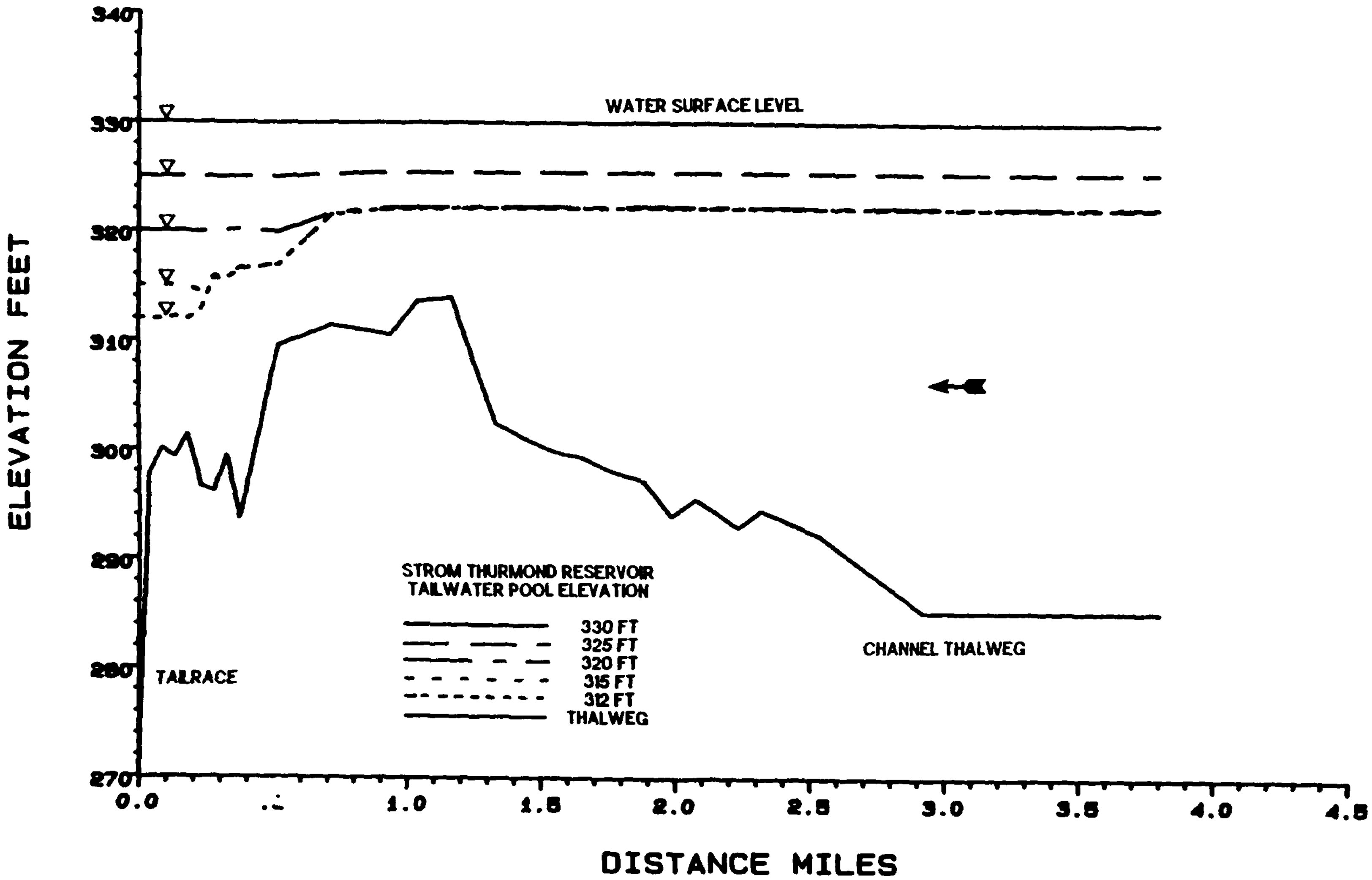


Figure 11. Water-surface profiles for Strom Thurmond Reservoir capacity pumpback, Q = 24,800 cfs (n = 0.03)

tailrace pool is anticipated for JSTR pool conditions approaching minimum levels. The longitudinal velocity profiles for capacity pumpback for modeled conditions are shown in Figure 12.

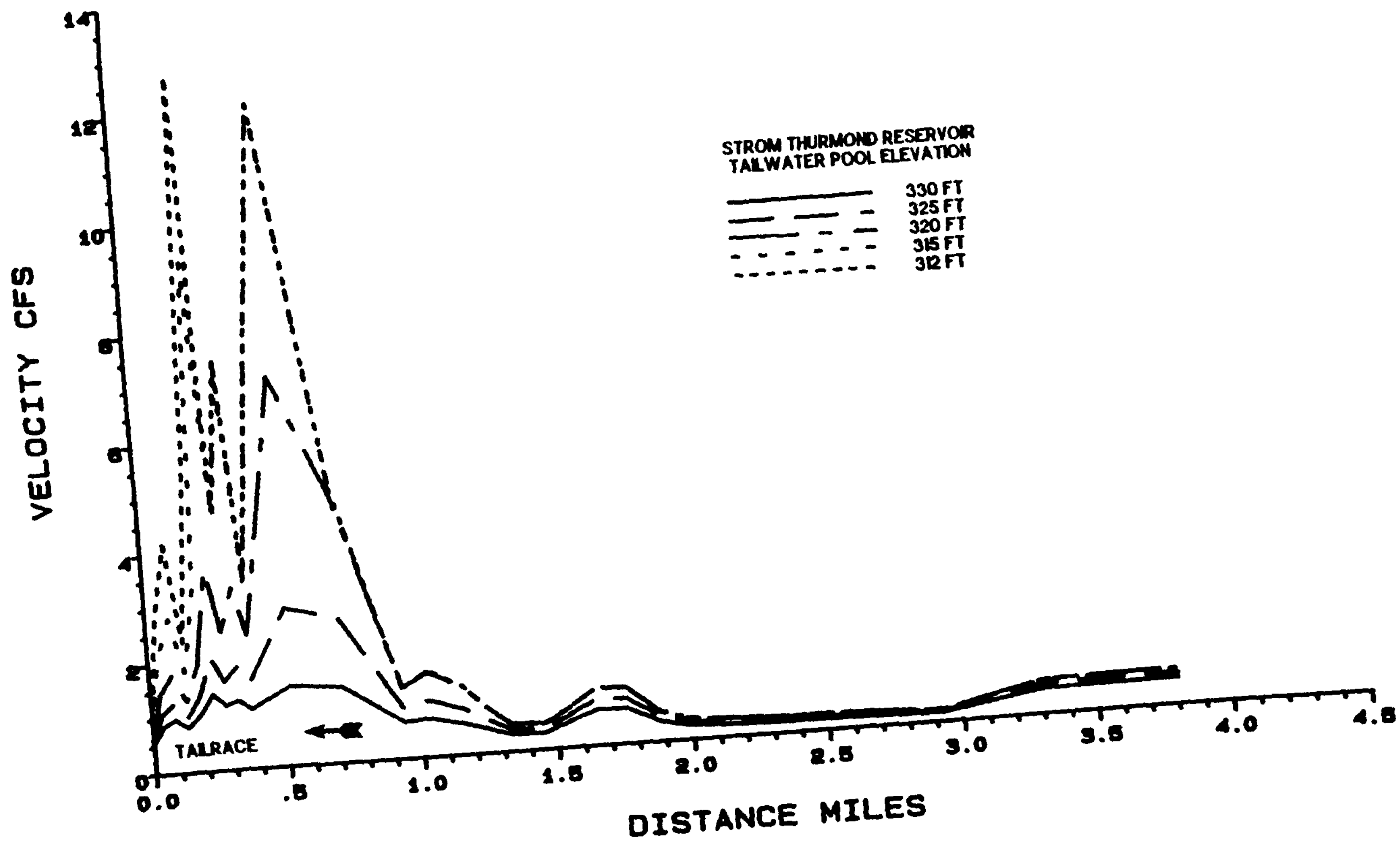


Figure 12. Velocity profiles for Strom Thurmond Reservoir capacity pumpback, Q = 24,800 cfs (n = 0.03)

PART V: NUMERICAL MODEL SIMULATION WITH CHANNEL IMPROVEMENT

Channel Improvement

25. The anticipated hydraulic conditions associated with capacity pumpback and generation flows with the existing channel configuration will significantly limit project operation. The following section outlines criteria for improving the capacity of the existing channel. For the purposes of this investigation, the minimal target velocity chosen as a basis for channel modification was 2 fps. This velocity objective was identified as being realistically obtainable through the channelization ofthe RBR tailrace, and is therefore referenced for analytical and comparative purposes. The minimum amount of excavation to reduce velocities to less than 2 fps during capacity pumpback can be estimated assuming level pool and average velocity conditions. An estimated excavation volume was calculated by averaging the excavation areas required to reduce velocities to 2 fps on adjacent cross sections for a given pool elevation and multiplying by the distance between the cross sections. The calculated excavation volumes to reduce approach velocities to 2 fps or less for capacity pumpback of 24,800 cfs for various JSTR pool elevations are shown in Table 3.

26. The relationship between excavation volume required to maintain average velocities less than 2 fps during capacity pumpback flows and JSTR pool elevations can be broken up into three regions. For pool elevations ranging from 330 to 327 ft, little or no excavation is required to meet the velocity ceiling. The second region encompasses pool levels ranging from 326 through 321 where removal of about 116,000 cubic yds of material will enable an addition foot drop in reservoir level to occur without average velocities exceeding 2 fps. The final region applies for all pool levels below 320 ft where excavation of about 257,000 cubic yds of material will enable an additional foot drop in reservoir level to occur before the velocity target is exceeded.

27. An estimate of the improved channel dimensions can be determined by assuming a trapezoidal channel cross-section with side slopes of 1:5. The area/stage relationship for this channel section is as follows:

$$A = BX + 5X^2$$

Table 3
Total Excavated Volume of Material Required to Achieve Velocities Objectives for Various JSTR Pool Levels

JSTR Pool Level (ft)	Volume of Material (1,000 cu. yd)	JSTR Pool Level (ft)	Volume of Material (1,000 cu. yd)
311	3192	321	732
312	2880	322	619
313	2605	323	511
314	2396	324	400
315	2159	325	282
316	1927	326	164
317	1674	327	46
318	1392	328	0
319	1106	329	0
320	882	330	0

where

A = Area (sq ft)

X = Stage (ft)

B = Bottom width (ft)

If the continuity relationship Q = VA is solved for area in terms of the the design pumpback flow rate divided by the target velocity, the equation is reduced to an equation of two unknowns (B and X). From this relationship, specifying the design stage will yield the corresponding bottom and top width of the design channel. Several design channels sufficient to meet study flow objectives are listed in Table 4.

28. The limiting condition for meeting velocity objectives occurred during capacity pumpback flow at minimum pool conditions. The design channel that closely matched the existing width of JSTR within the study area is a trapezoidal channel with a bottom width of 800 ft. An excavated channel invert at 298 ft would be required to maintain a depth of flow of 14.2 ft during minimum pool conditions in order to meet flow objectives. This would require a channel top width of at least 1,122 ft at normal tailwater pool conditions.

Table 4

Trapezoidal Channel Dimensions to Meet Study Flow Objectives

Stage (ft)	Channel Bottom Width (ft)	Channel Top Width @ Minimum Pool (ft)	Channel Top Width @ Normal Pool (ft)
8.6	1400	1486	1666
9.9	1200	1299	1479
11.7	1000	1117	1297
14.2	800	942	1122
18.0	600	780	960

29. The proposed channel improvement consisted of a trapezoidal channel, excavated to an invert elevation of 298 ft, with a bottom width of 800 ft, and extended from Transect L750 through Transect L6500 was modeled for capacity pumpback conditions at JSTR pool elevations of 330, 325, 320, 315, and 312. The northern limit of the channel improvement was established on Transect L750 because of limited channel capacity (Figure A3). The excavated region was extended through transect L6500 based upon preliminary simulations of capacity pumpback flow. The natural invert elevation of 308 ft on this Transect resulted in velocities greater than 2 fps during minimum pool conditions despite a relatively wide channel width. The channel improvement is centered between the Georgia and South Carolina shores in the northern half of the excavation region. The southern end of the channel improvement tends towards the Georgia shore in order to tie into the existing channel (Figure 13).

Predictive Numerical Model Results with Channel Improvement

30. The removal of bed material from JSTR is expected to change the frictional resistance of the channel. The proposed excavation would remove much of the cobble and boulder sized material remaining from project construction and vegetation cover that has developed over much of the study region. Also, the energy losses associated with channel form would be reduced by straightening the channel alignment and removing the crest of the deposits. The resistance of the improved channel cannot be determined analytically. Therefore, both a high and low channel resistance coefficient (0.02, 0.03) were employed throughout the remainder of this study. These figures were used

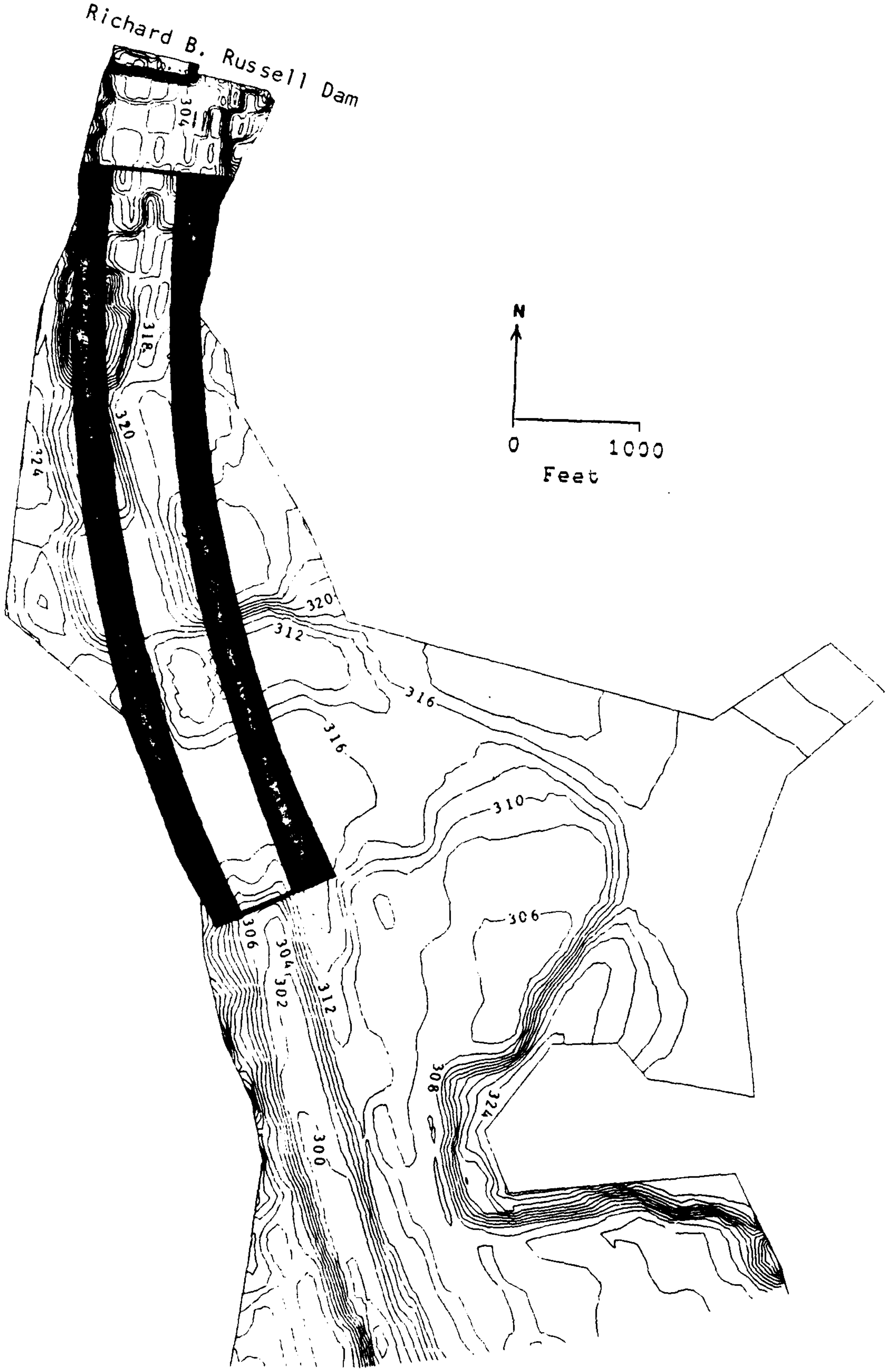


Figure 13. Proposed channel improvement

to bracket the anticipated response of the proposed channel improvements to the hydraulic conditions under study. The worst-case scenario involving no change in the frictional resistance of the channel (n = 0.03) are discussed in the body of this report while the projections assuming a smaller frictional resistance (n = 0.02) are included in Figures B1-B20.

31. The proposed channel improvement resulted in favorable flow conditions for all tailwater pool scenarios under capacity pumpback conditions. The water-surface profiles generated for all reservoir stages indicated no significant draw down in the tailrace area (Figure 14). The velocities throughout the excavated region approached 2 fps as the reservoir level approached el 312 ft (Figure 15). Velocities exceeding 2 fps were predicted to occur at the contraction between the two major embayments and just north of the excavation area. Additional excavation in these areas would be required to reduce approach velocities to 2 fps as JSTR levels approached minimum pool conditions. The proposed channel thalweg throughout the study area was much more uniform than existing conditions. The excavated volume of material associated with the proposed channel improvement was in excess of 3.3 million cubic yards.

32. The proposed channel improvement modeled under capacity generation conditions resulted in only minor backwater effects in the tailrace region (Figure 16). The tailwater stage was 4.5 ft higher than the minimum reservoir pool conditions during these flow simulations. The tailrace stage rise was less than one foot for all reservoir stages greater than 320 ft. The average cross-sectional velocities remain under 2 fps for reservoir stages greater than 320 ft with the exception of the contraction between the two major embayment and the area around the buoy line (Figure 17). For reservoir levels below 315 ft, the maximum channel velocity during capacity generation exceeds 4 fps.

33. Four additional alternative channel configurations were investigated for capacity pumpback and generation conditions to determine the trade-off between excavation volume and resultant flow conditions. The alignment and width of the proposed channel improvement remained identical to that described in paragraph 30. The channel invert was varied in each alternative to correspond with elevations of 300, 305, 307, and 310 ft.

34. Reducing the extent of the channel improvement by raising the channel invert resulted in increasing the velocity field for capacity pumpback

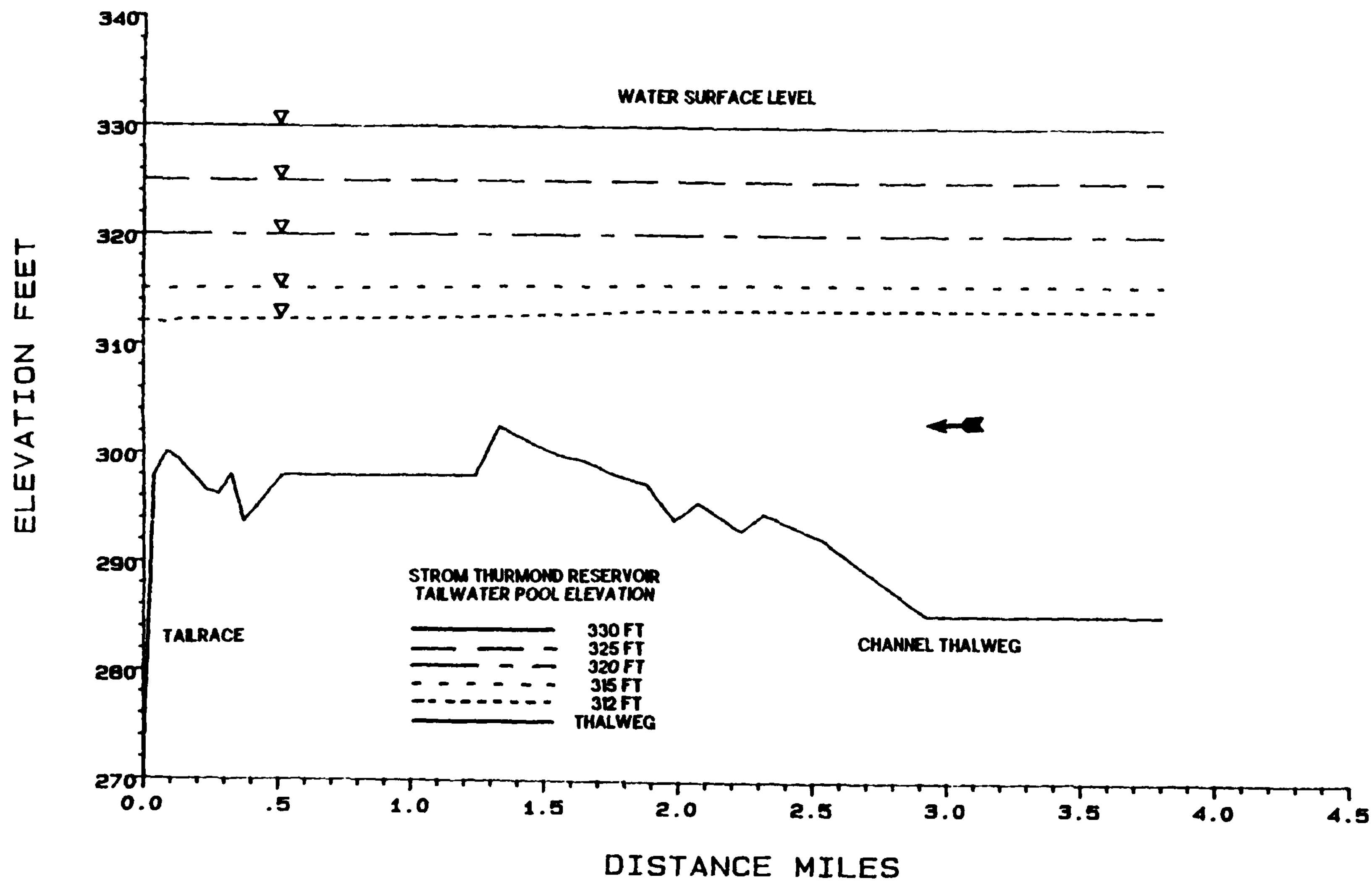


Figure 14. Water-surface profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 298 ft (n = 0.03)

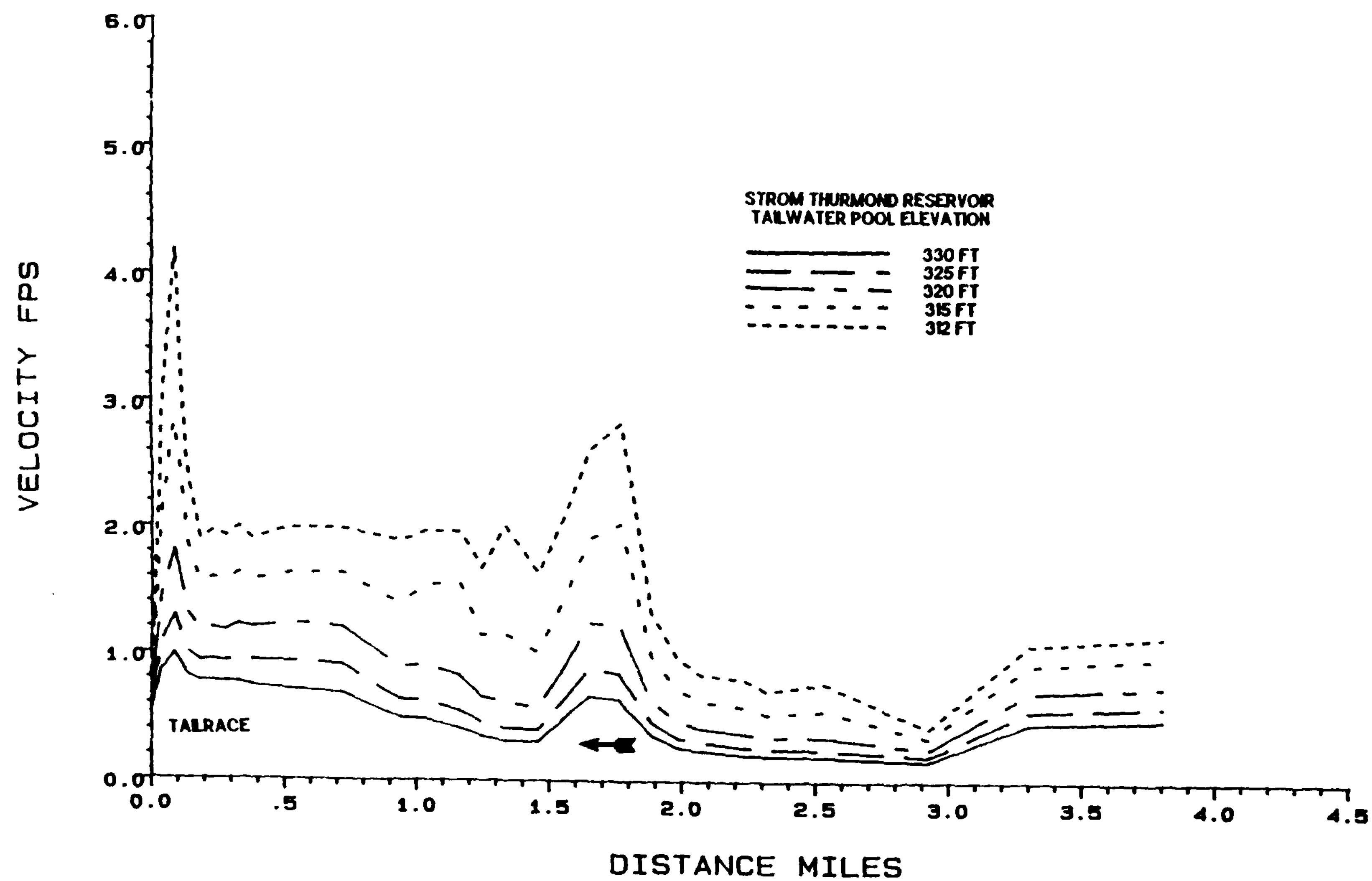


Figure 15. Velocity profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 298 ft (n = 0.03)

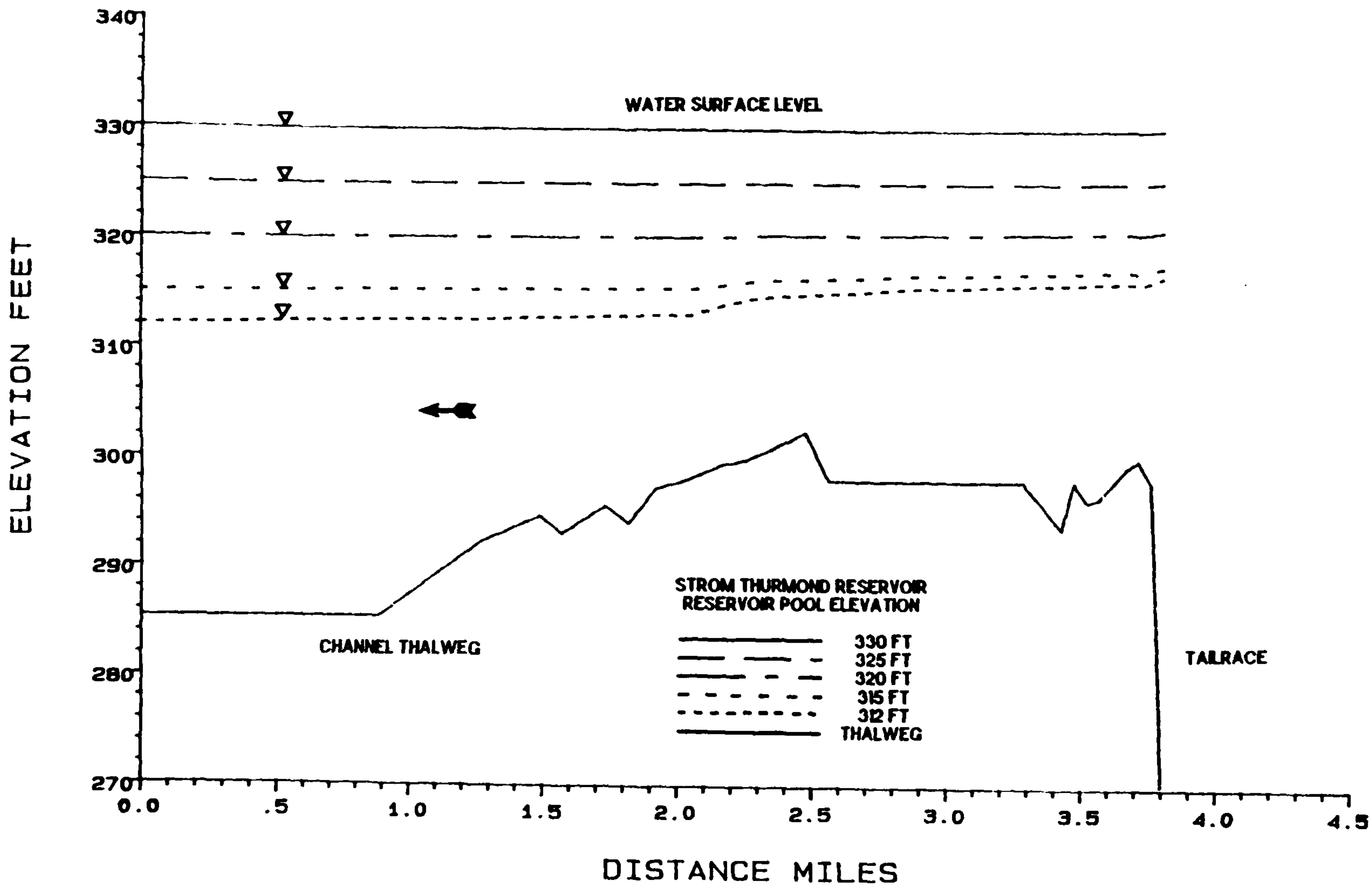


Figure 16. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 298 ft (n = 0.03)

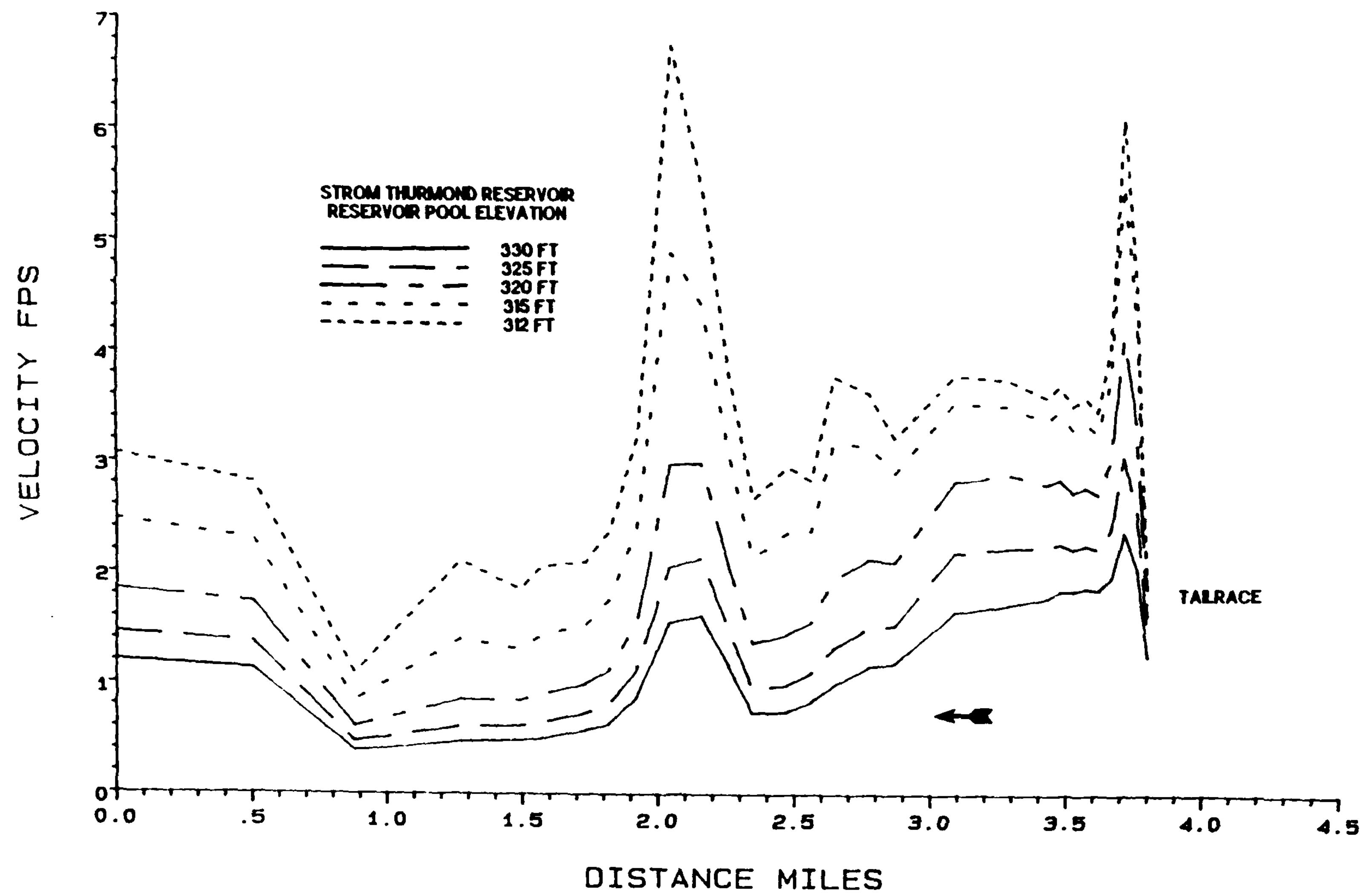


Figure 17. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 298 ft (n = 0.03)

flows. Approach velocities exceeded the objective of 2 fps for some JSTR stages greater than minimum pool. The resultant flow conditions for the trapezoidal channel improvement with an invert elevation of 300 ft were similar to the 298-ft channel improvement. The water-surface slopes for all conditions modeled were small (Figure 18). Velocities exceeded 2 fps only when the JSTR pool elevation was dropped to elevation 315 ft or less (Figure 19). The total volume of excavation associated with this channel improvement was 2.8 million cubic yards of material. For channel excavation to elevation 305 ft, water-surface slopes were small except at a pool elevation of 312 (Figure 20). Approach velocities began to exceed objectives when the JSTR pool fell below elevation 320 ft. At minimum tailwater pool, velocities approached 4 fps throughout the region one mile from the dam (Figure 21). A total excavated volume of 1.9 million cubic yards of material was required for this channel improvement. Dredging the afterbay channel to elevation 307 ft resulted in close to ideal flow conditions for tailwater pool elevations above 320 ft. Several feet of drawdown were modeled for reservoir levels below elevation 315 ft (Figure 22). Approach velocities as high as 5 fps were calculated for minimum tailwater conditions (Figure 23). The channel improvement alternative would require the removal of 1.50 million cubic yards of material. The final channel design studied involved excavation down to elevation 310 ft that resulted in removal of 0.98 million cubic yards of material. Again, drawdown was evident for the two lowest pool elevations tested (Figure 24). Approach velocities exceeded 2 fps when the JSTR level dropped below elevation 323 ft (Figure 25). Severe flow conditions developed for this alternative when JSTR pool levels approached elevation 315 ft. Significant tailrace drawdown and approach velocities exceeding 5 fps were identified for these flow conditions. The cumulative excavated volume as a function of distance from the dam is listed in Table 5 and illustrated in Figure 26 for the five alternative channel improvements studied.

35. The influence of alternative channel improvement designs on capacity generation were investigated for reservoir pool elevations 330, 325, 320, 315, and 312 ft as shown in Figures 27-34. The tailwater pool setup was less than 2 ft for all channel designs with initial reservoir pool elevations greater than or equal to 320 ft. The tailwater pool setup associated with minimum reservoir pool conditions ranged from 2 to 10 ft with greater channel excavation resulting in smaller backwater effects. Average channel velocities

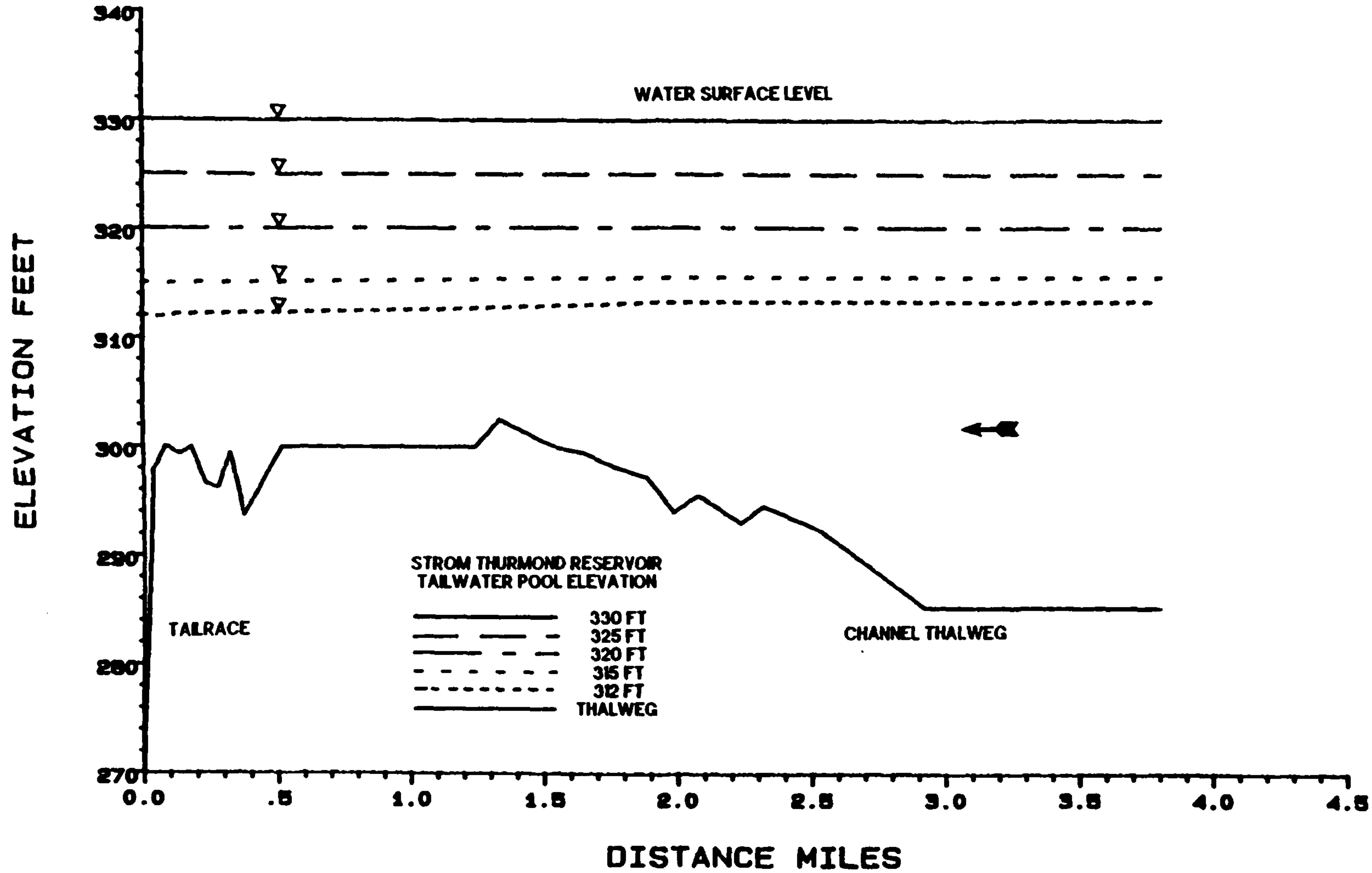


Figure 18. Water-surface profiles for Strom Thurmond Reservoir pumpback Q - 24,800 cfs, excavation 300 ft (n = 0.03)

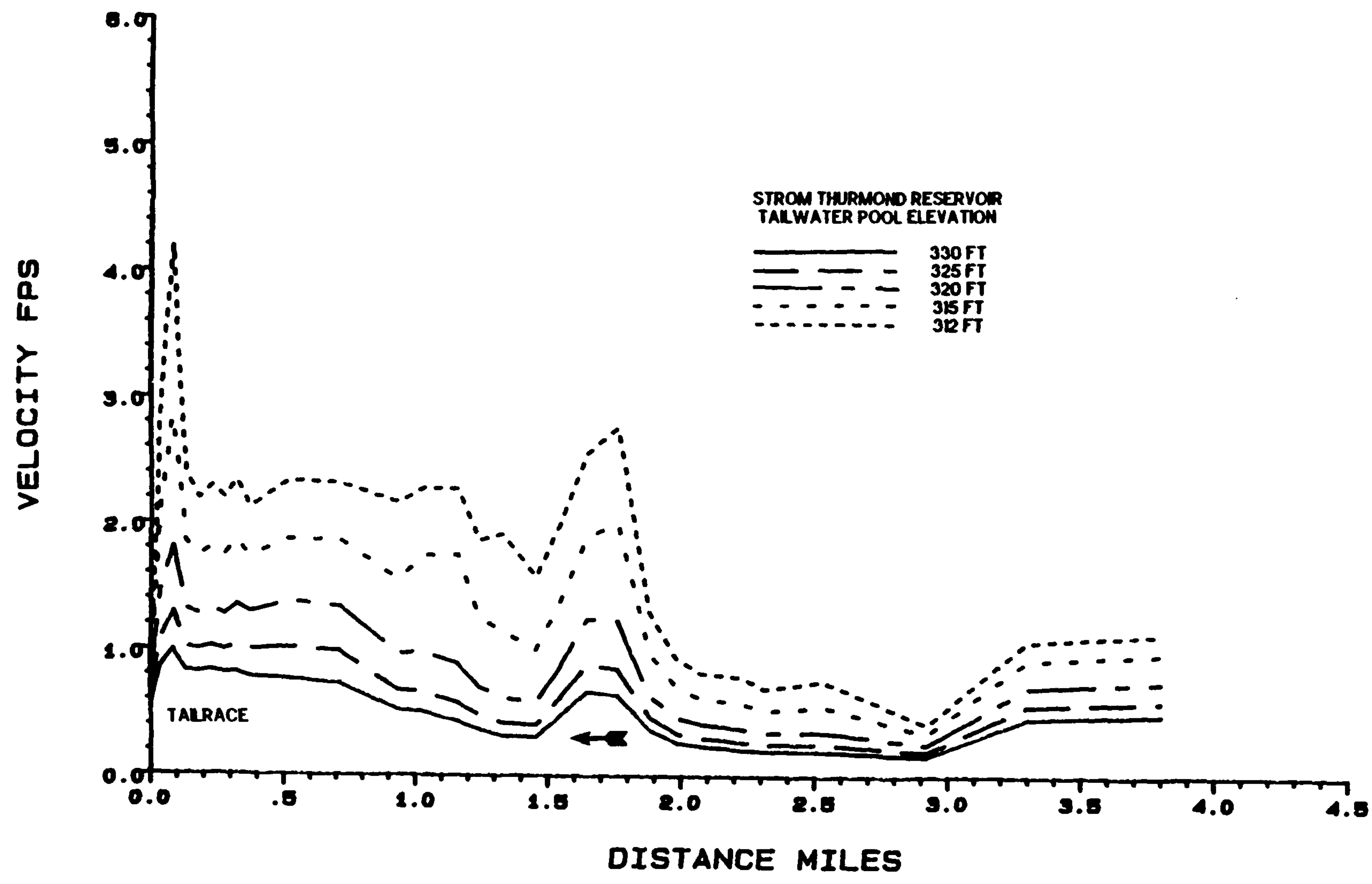


Figure 19. Velocity profiles for Strom Thurmond Reservoir pumpback Q - 24,800 cfs, excavation 300 ft (n = 0.03)

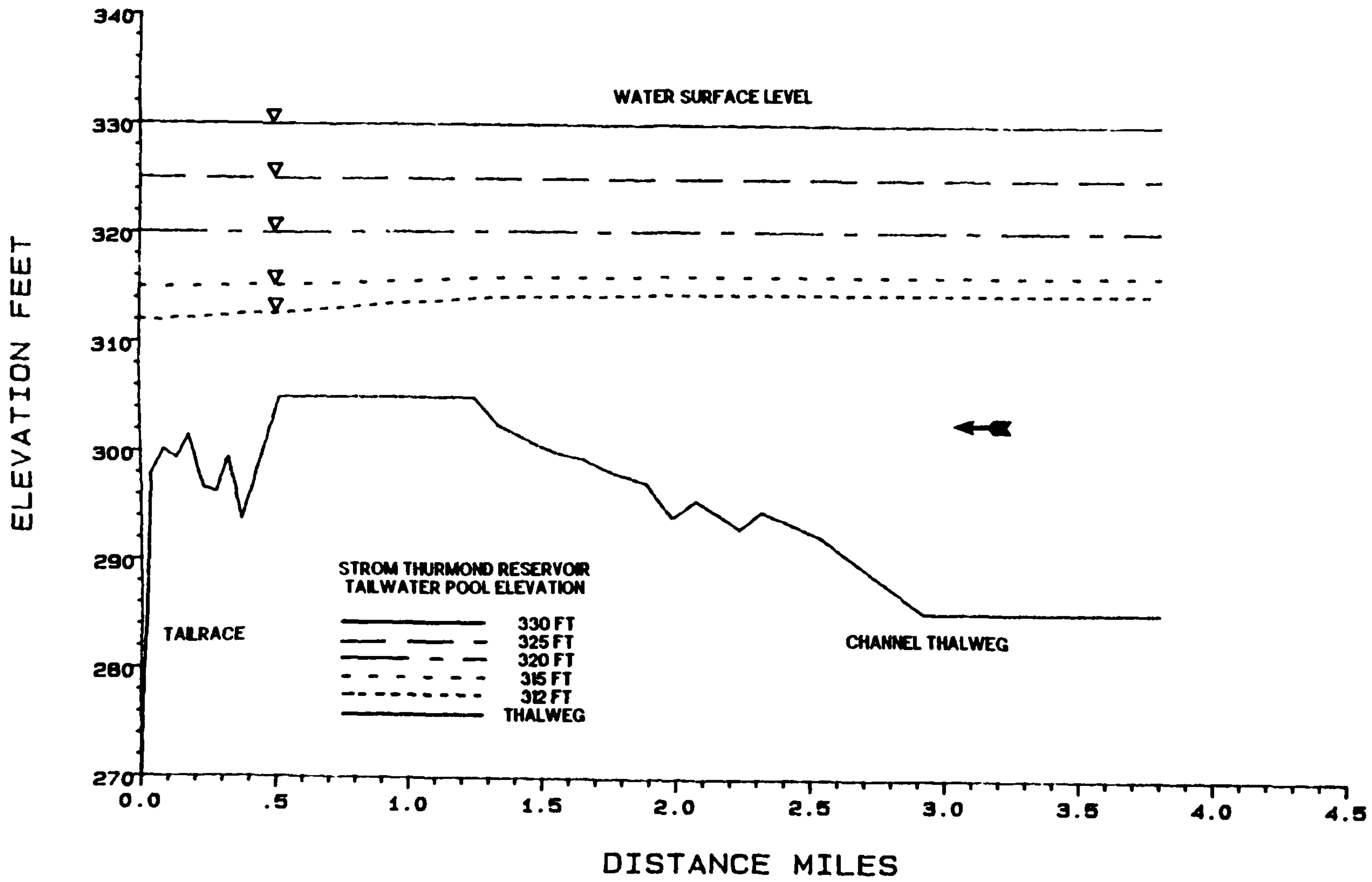


Figure 20. Water-surface profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 305 ft (n = 0.03)

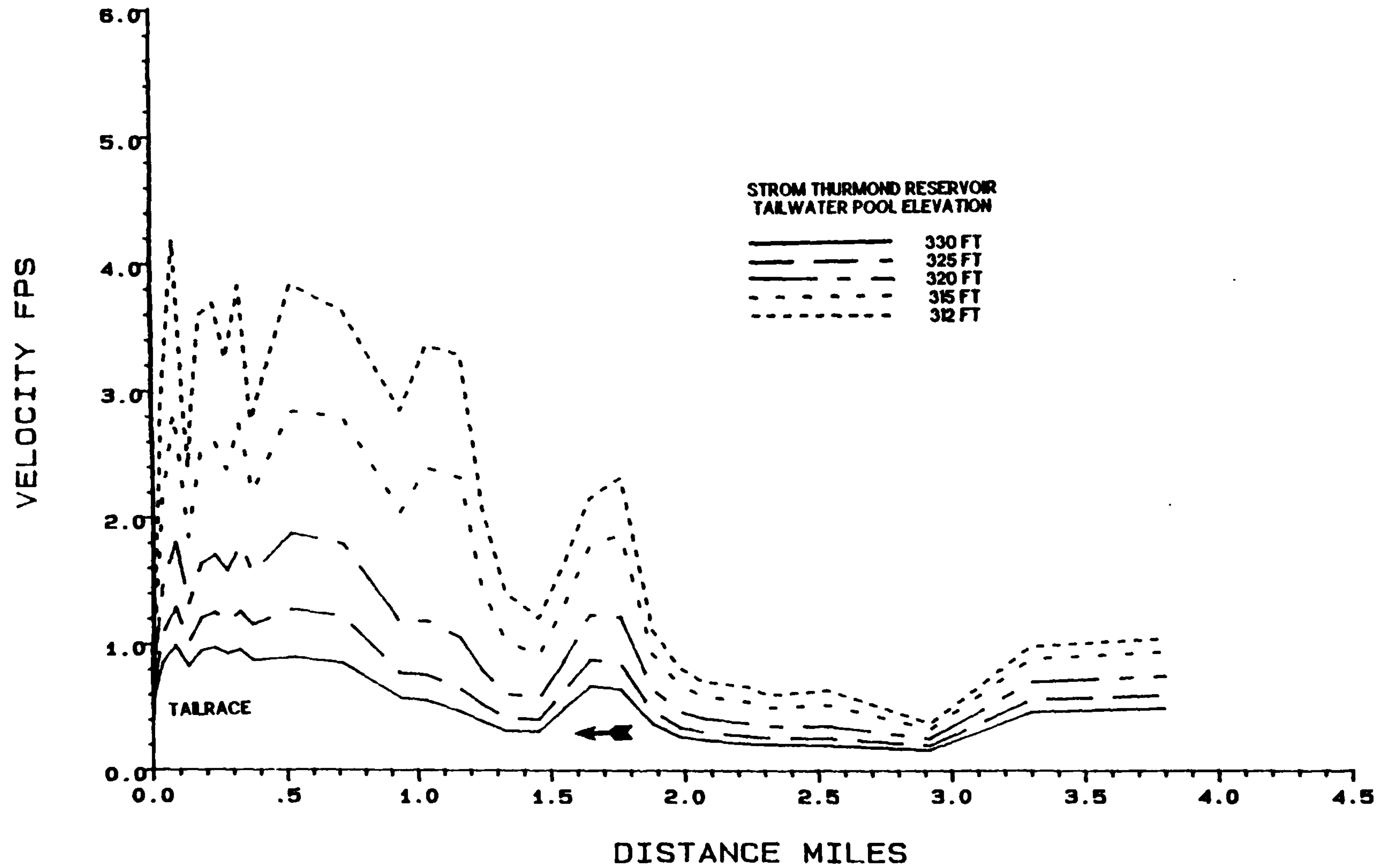


Figure 21. Velocity profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 305 ft (n = 0.03)

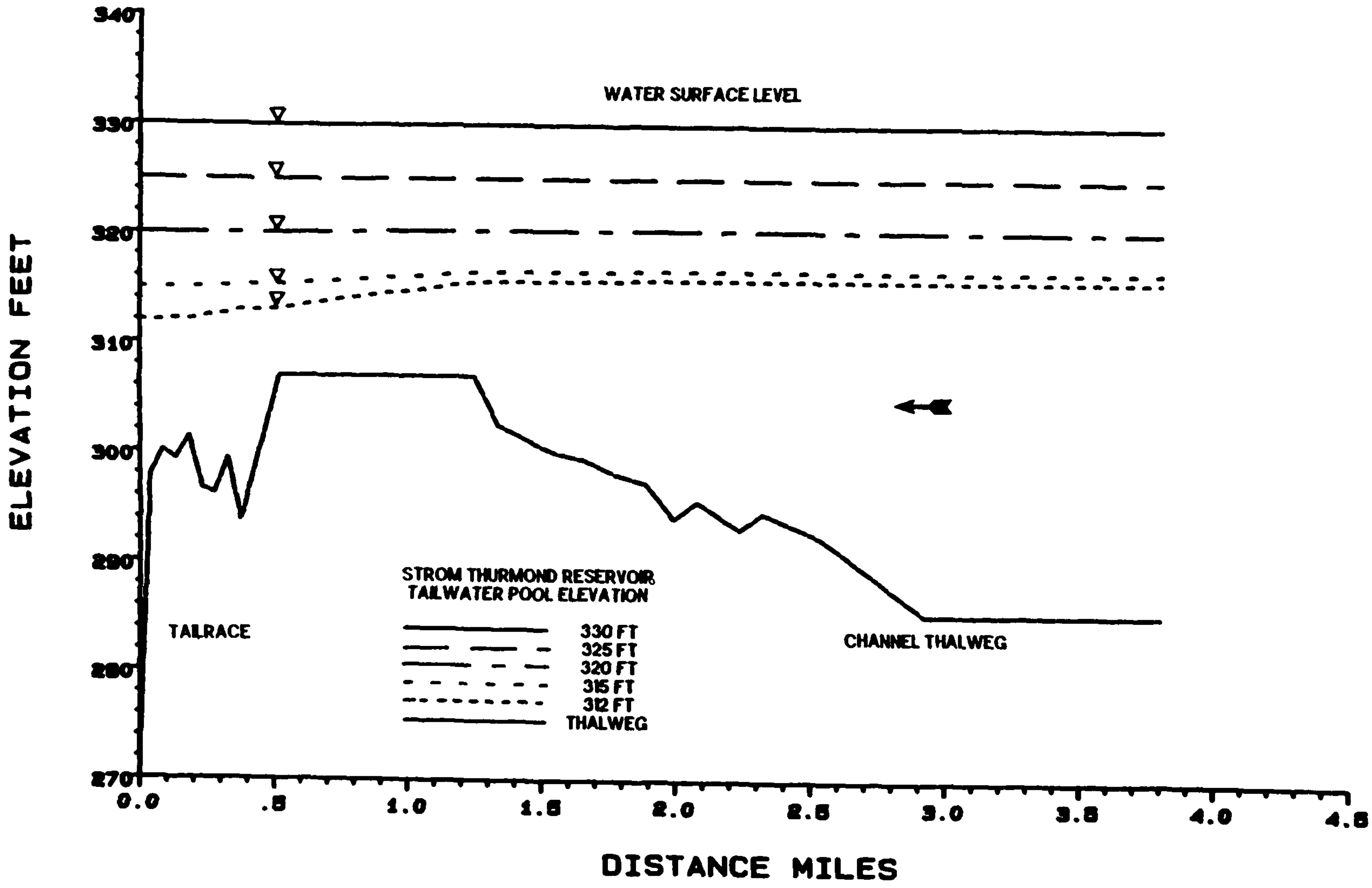


Figure 22. Water-surface profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 307 ft (n = 0.03)

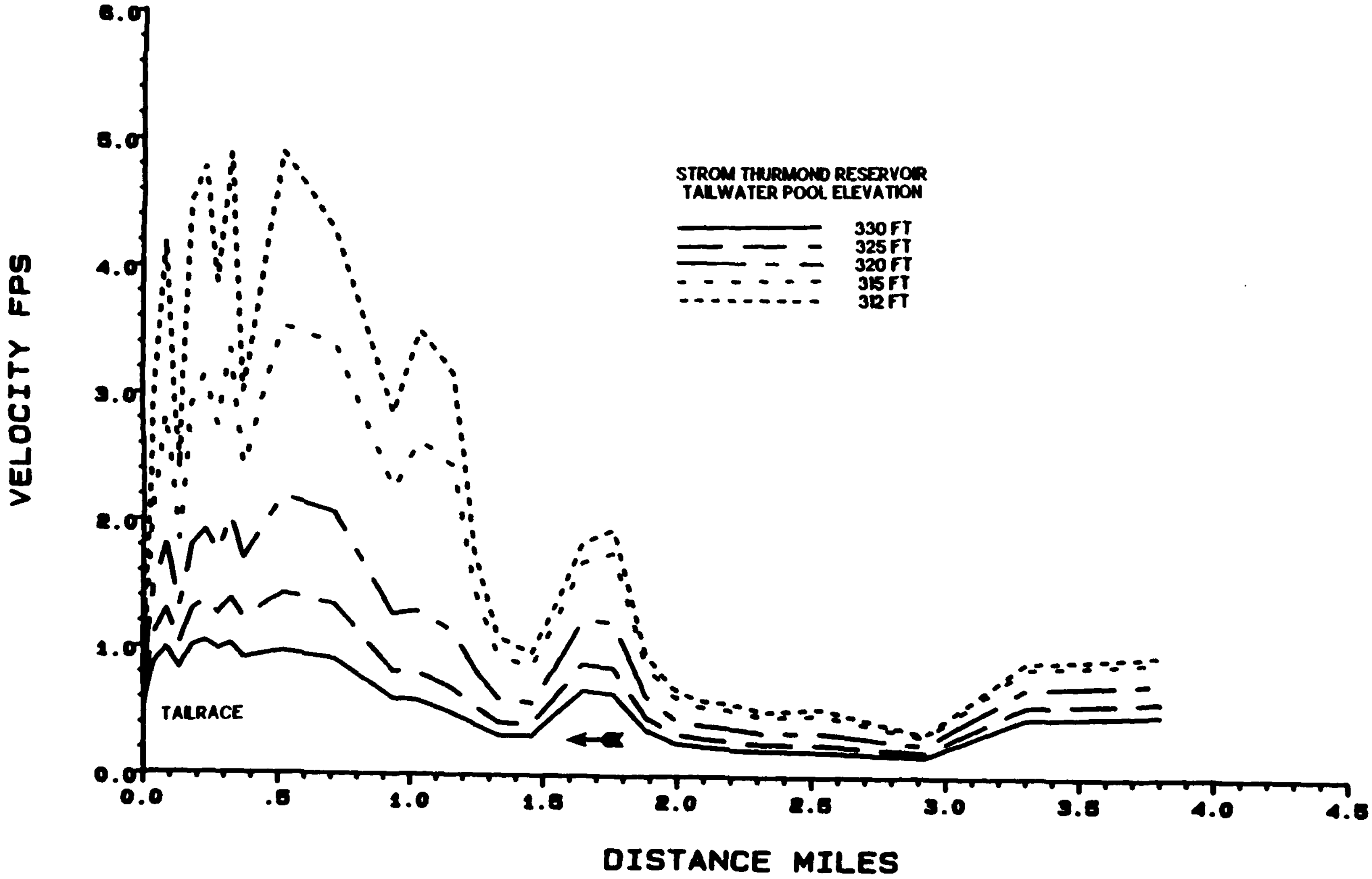


Figure 23. Velocity profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 307 ft (n = 0.03)

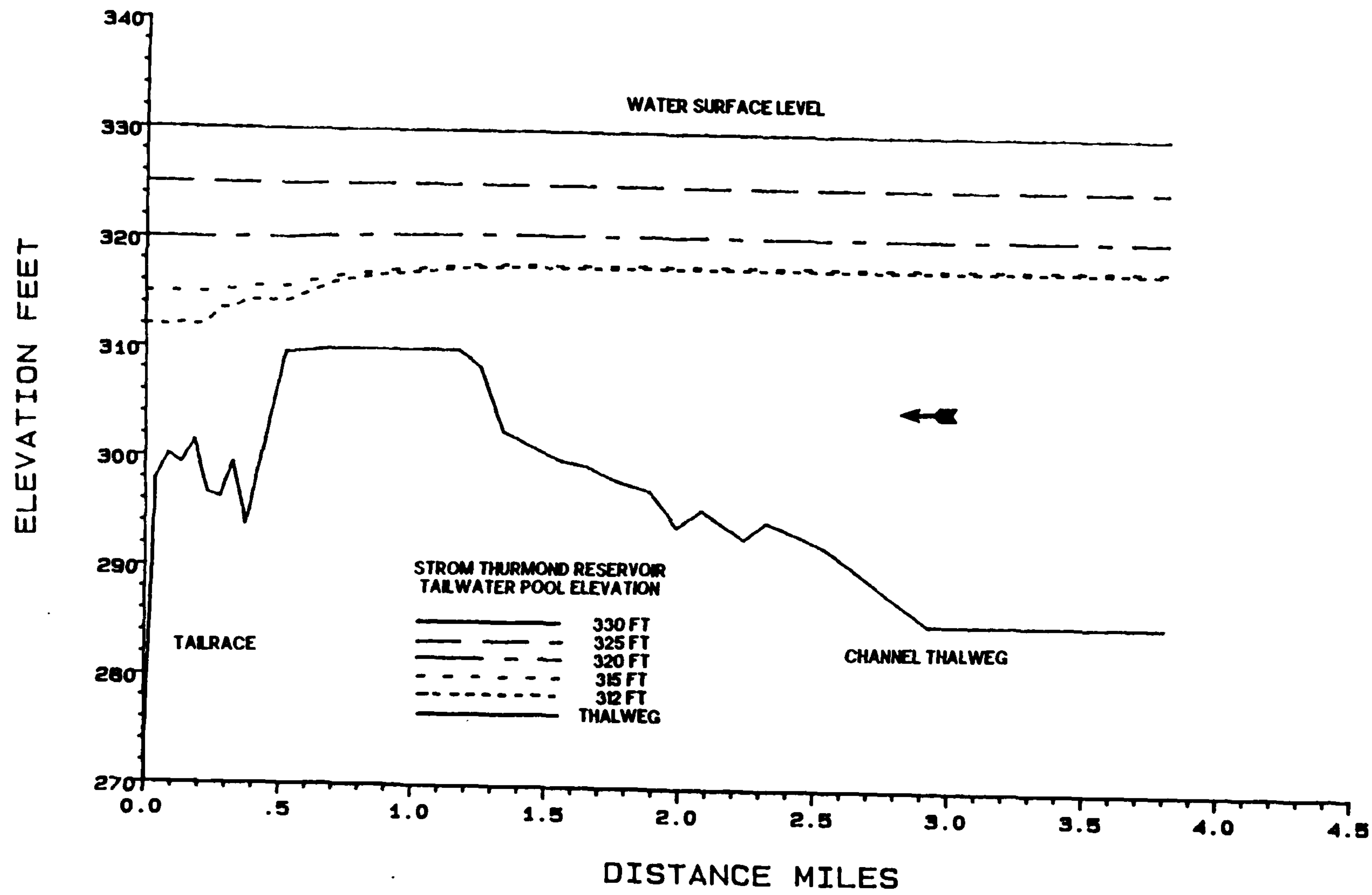


Figure 24. Water-surface profiles for Strom Thurmond Reservoir pumback Q = 24,800 cfs, excavation 310 ft (n = 0.03)

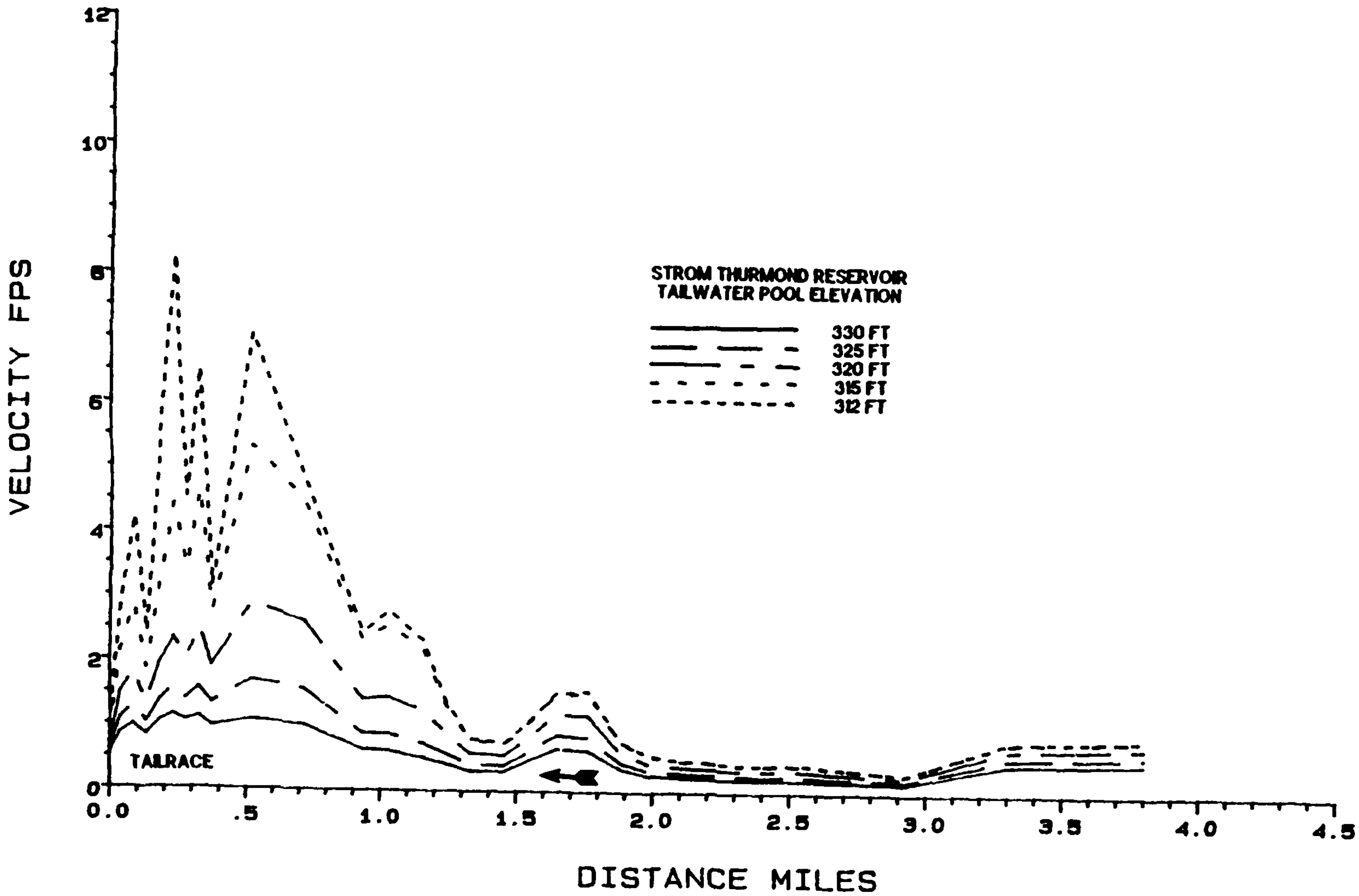


Figure 25. Velocity profiles for Strom Thurmond Reservoir pumpback Q - 24,800 cfs, excavation 310 ft (n = 0.03)

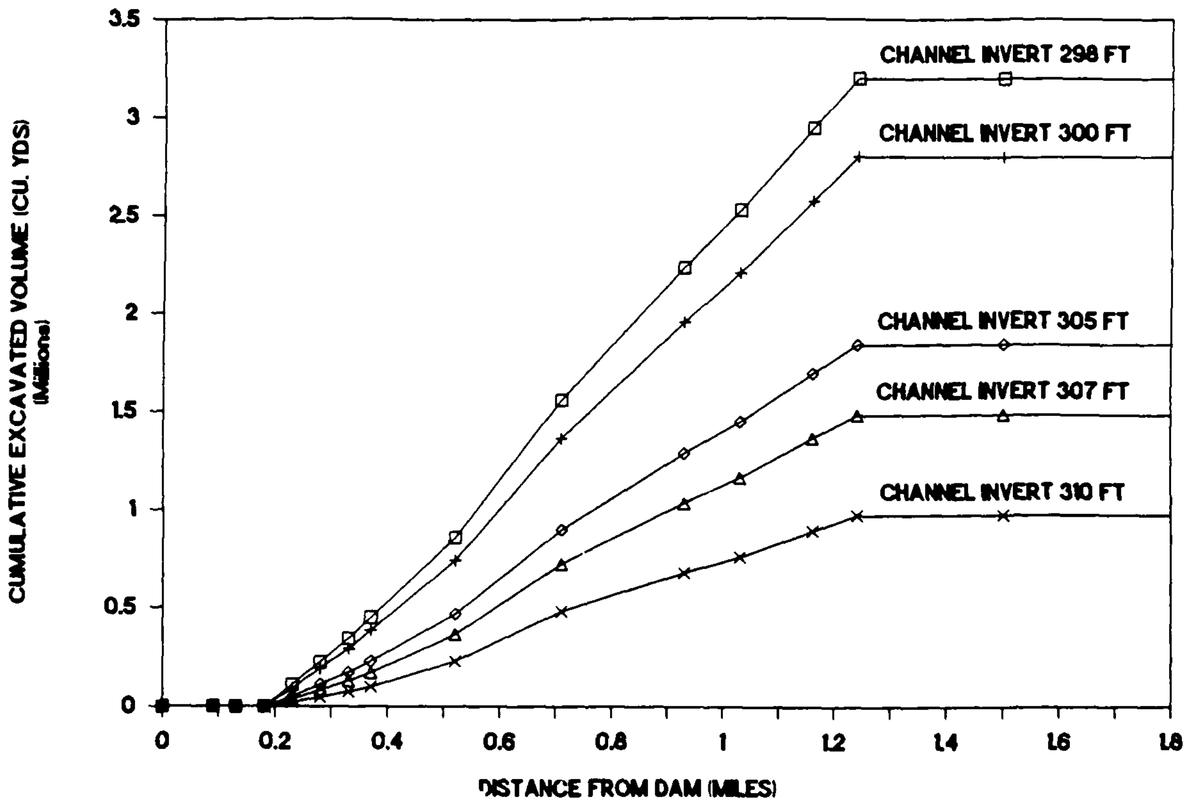


Figure 26. Cumulative excavated volume of channel improvement

ranged from 1 to 2 fps at normal pool conditions and from 2.5 to 8 fps at minimum pool conditions throughout the channel improvement region.

Table 5

Cumulative Excavated Volume of Channel Improvement

Distance Miles	Excavated Volume in 1,000 cu. yards Invert 298	Invert 300	Invert 305	Invert 307	Invert 310
0.0	0	0	0	0	0
0.09	0	0	0	0	0
0.13	0	0	0	0	0
0.18	0	0	0	0	0
0.23	110	92	50	35	20
0.28	227	192	112	84	50
0.33	342	291	171	129	75
0.37	450	383	228	172	101
0.52	860	742	467	366	231
0.71	1561	1364	898	724	481
0.93	2238	1958	1291	1039	682
1.03	2528	2211	1453	1167	761
1.16	2945	2579	1704	1372	899
1.24	3200	2803	1853	1492	977
2.39	3200	2803	1853	1492	977

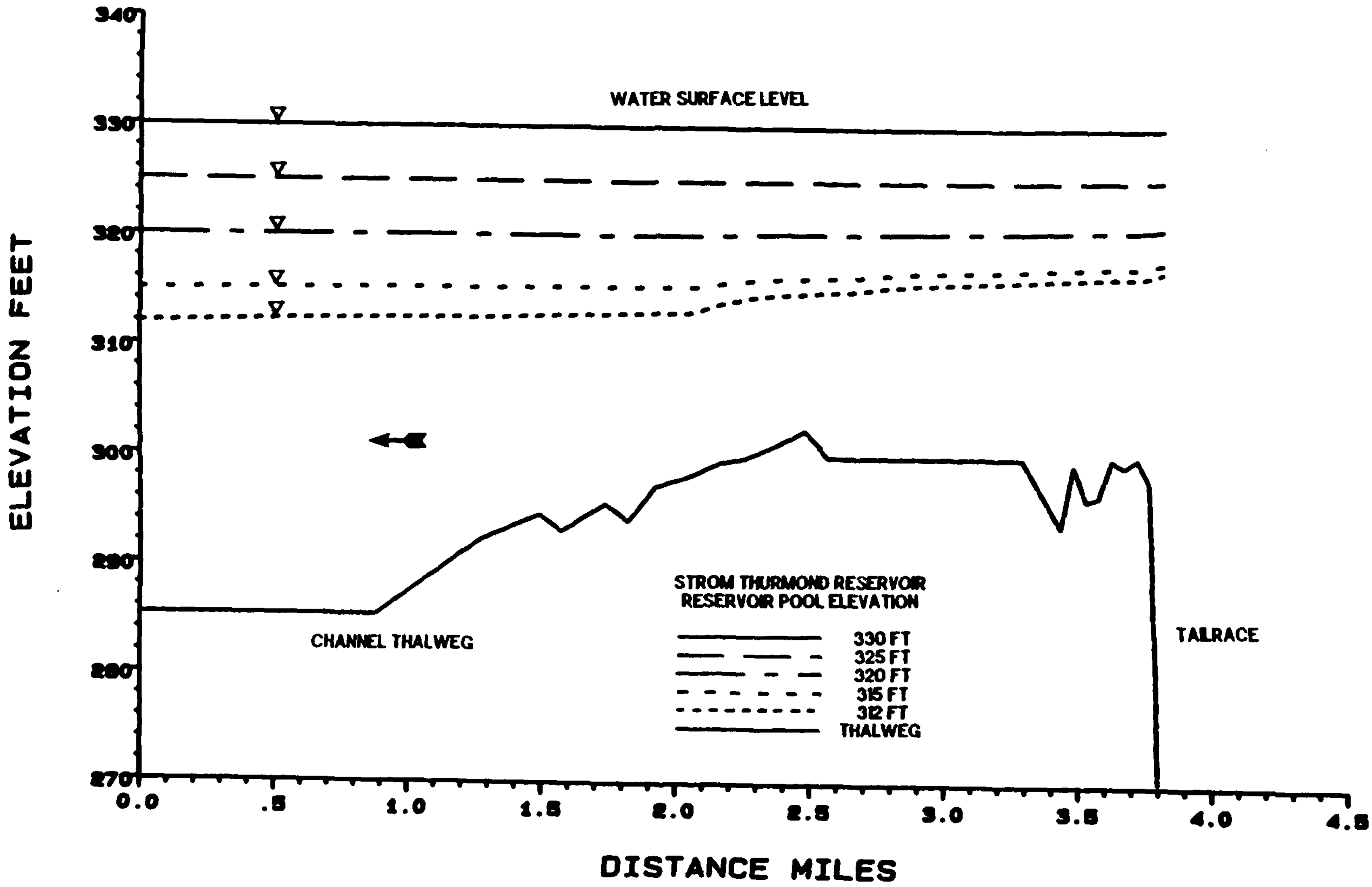


Figure 27. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 300 ft (n = 0.03)

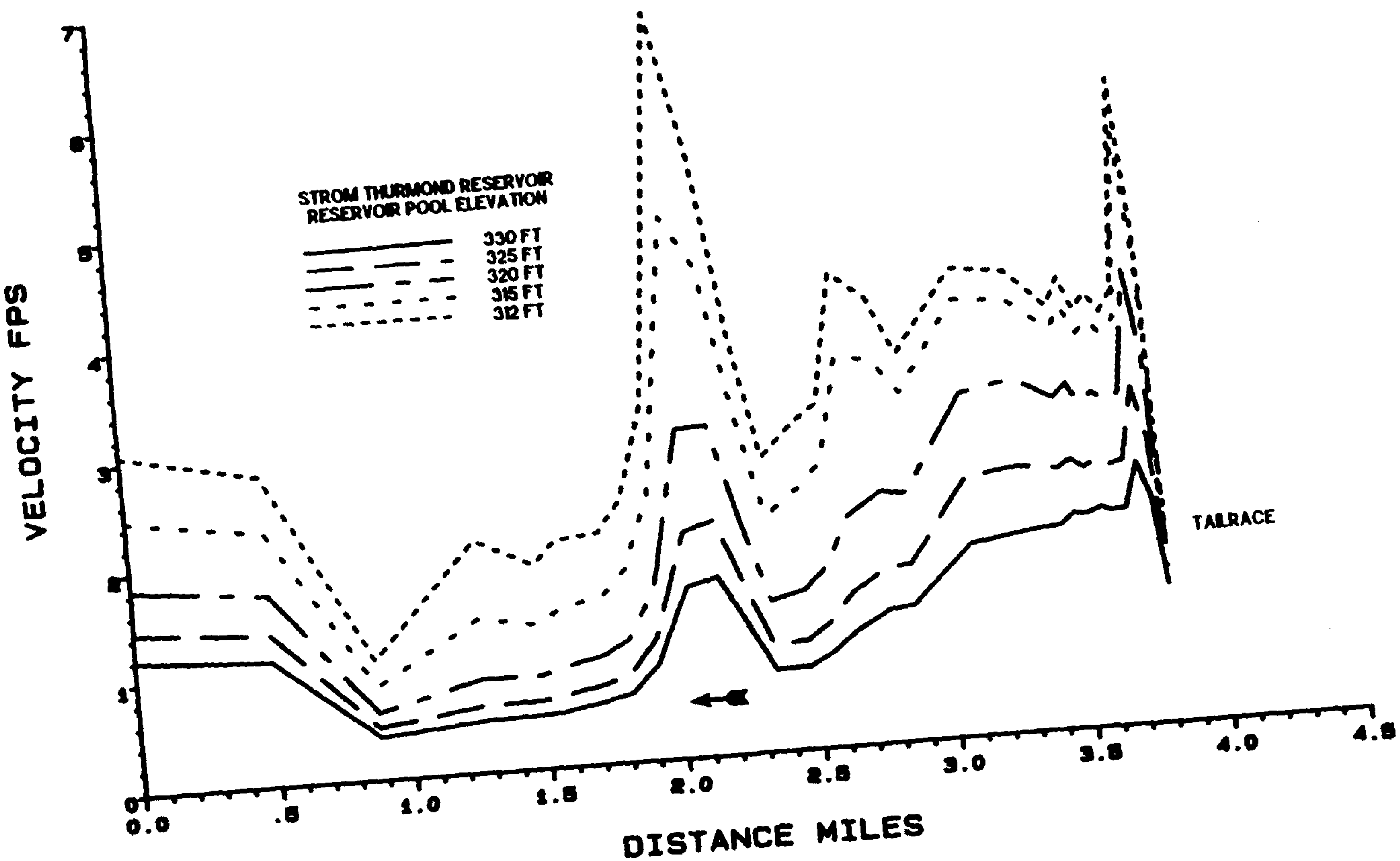


Figure 28. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 300 ft (n = 0.03)

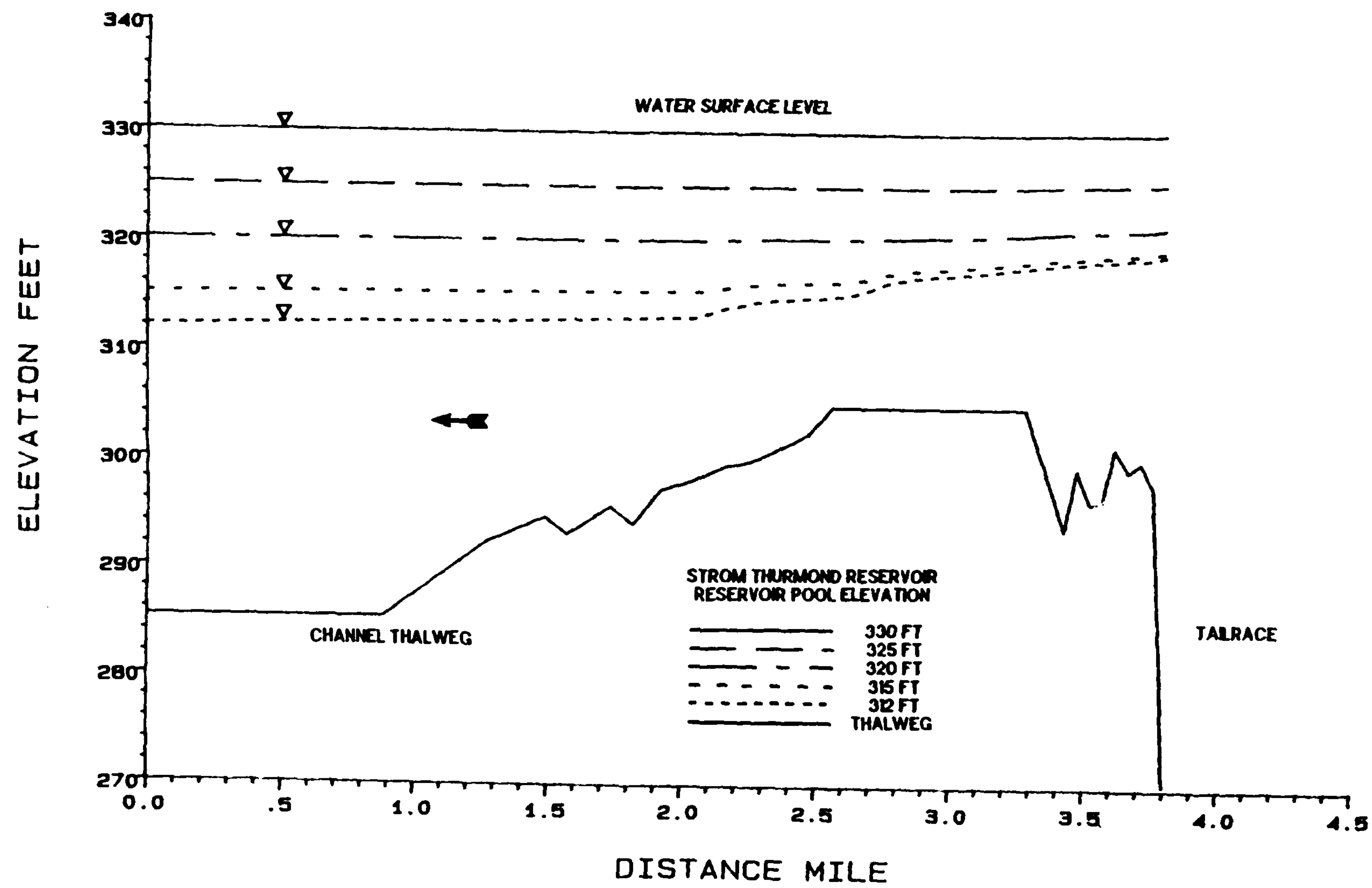


Figure 29. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 305 ft (n = 0.03)

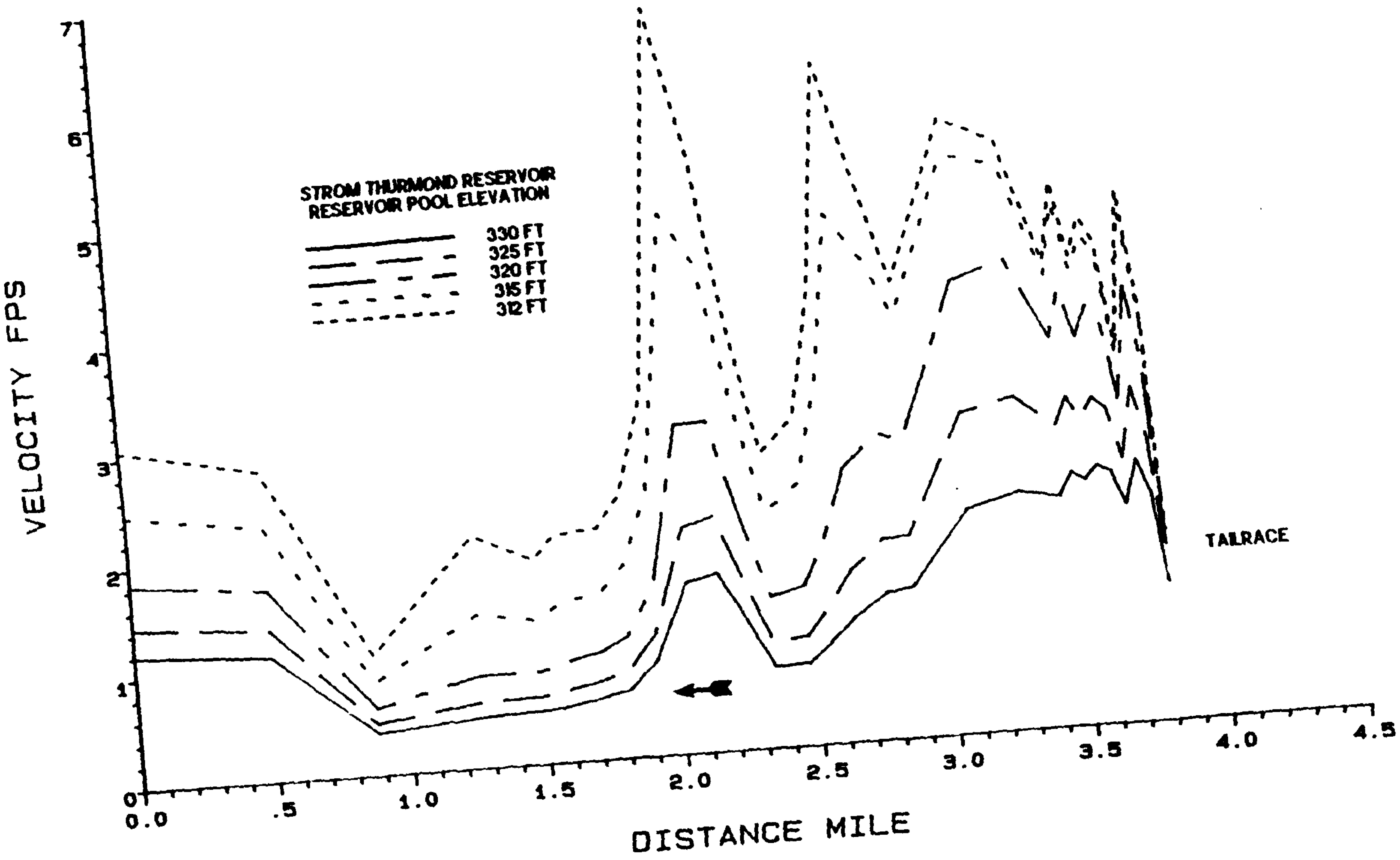


Figure 30. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 305 ft (n = 0.03)

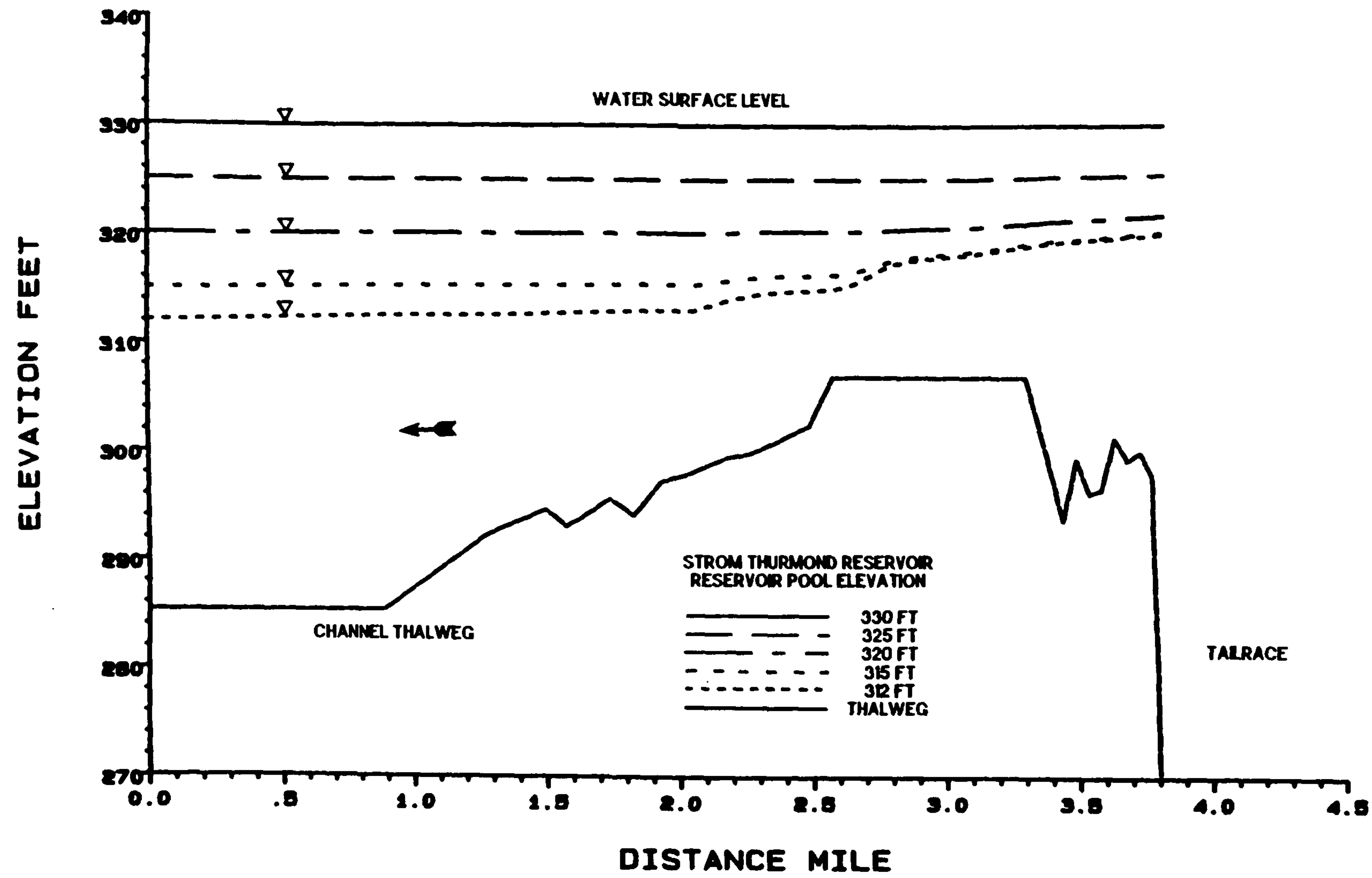


Figure 31. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 307 ft (n = 0.03)

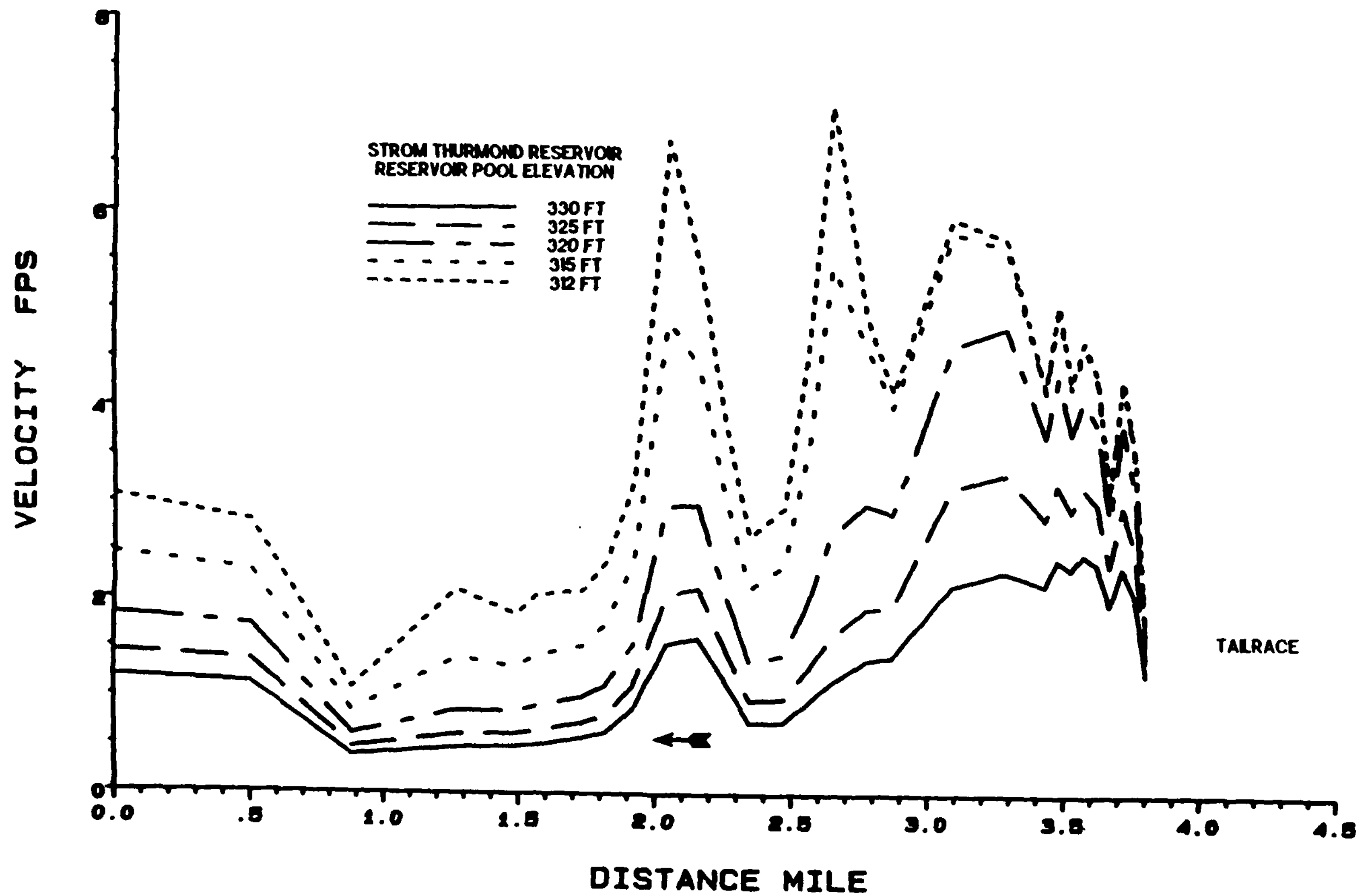


Figure 32. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 307 ft (n = 0.03)

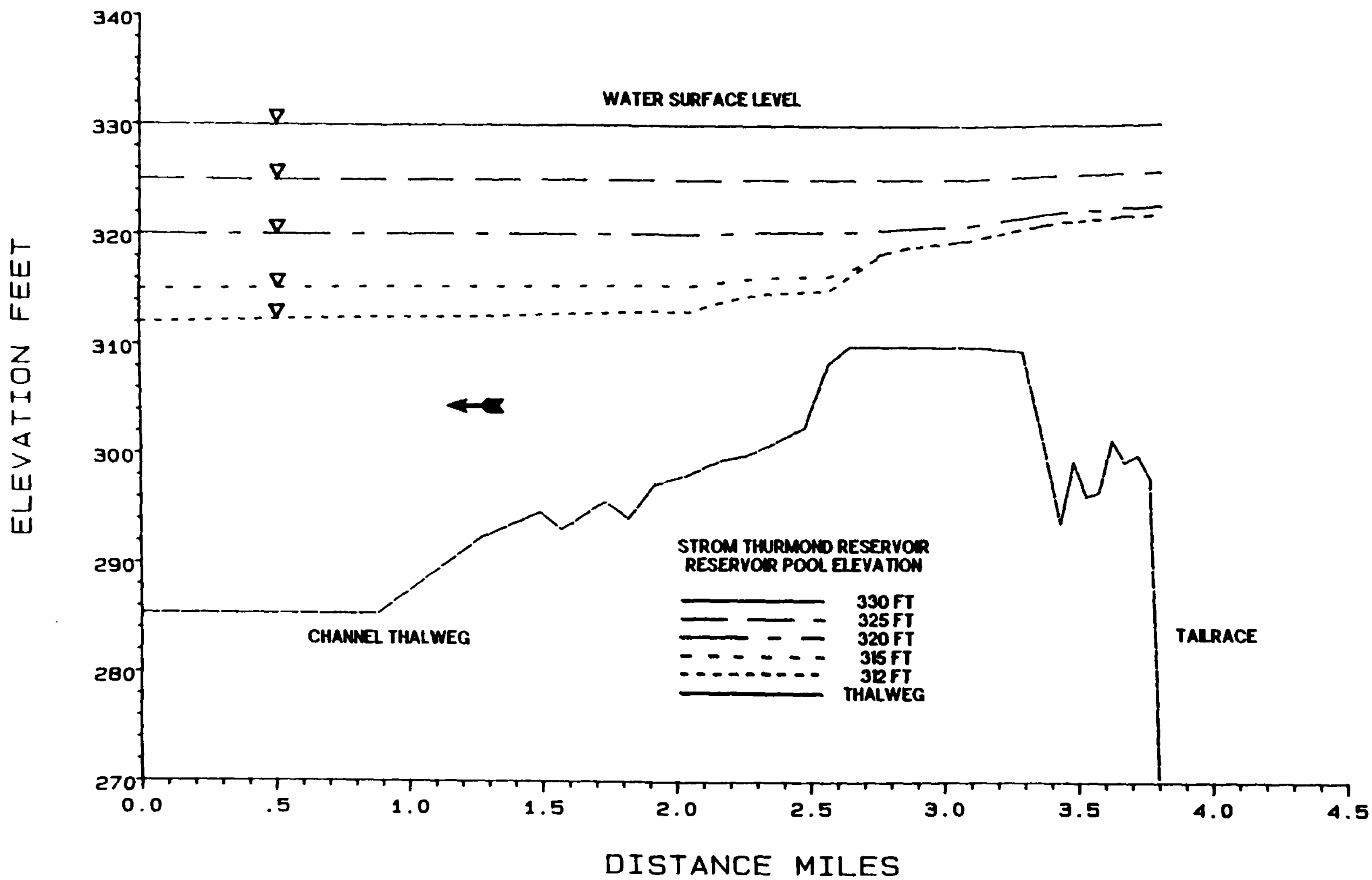


Figure 33. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 310 ft (n = 0.03)

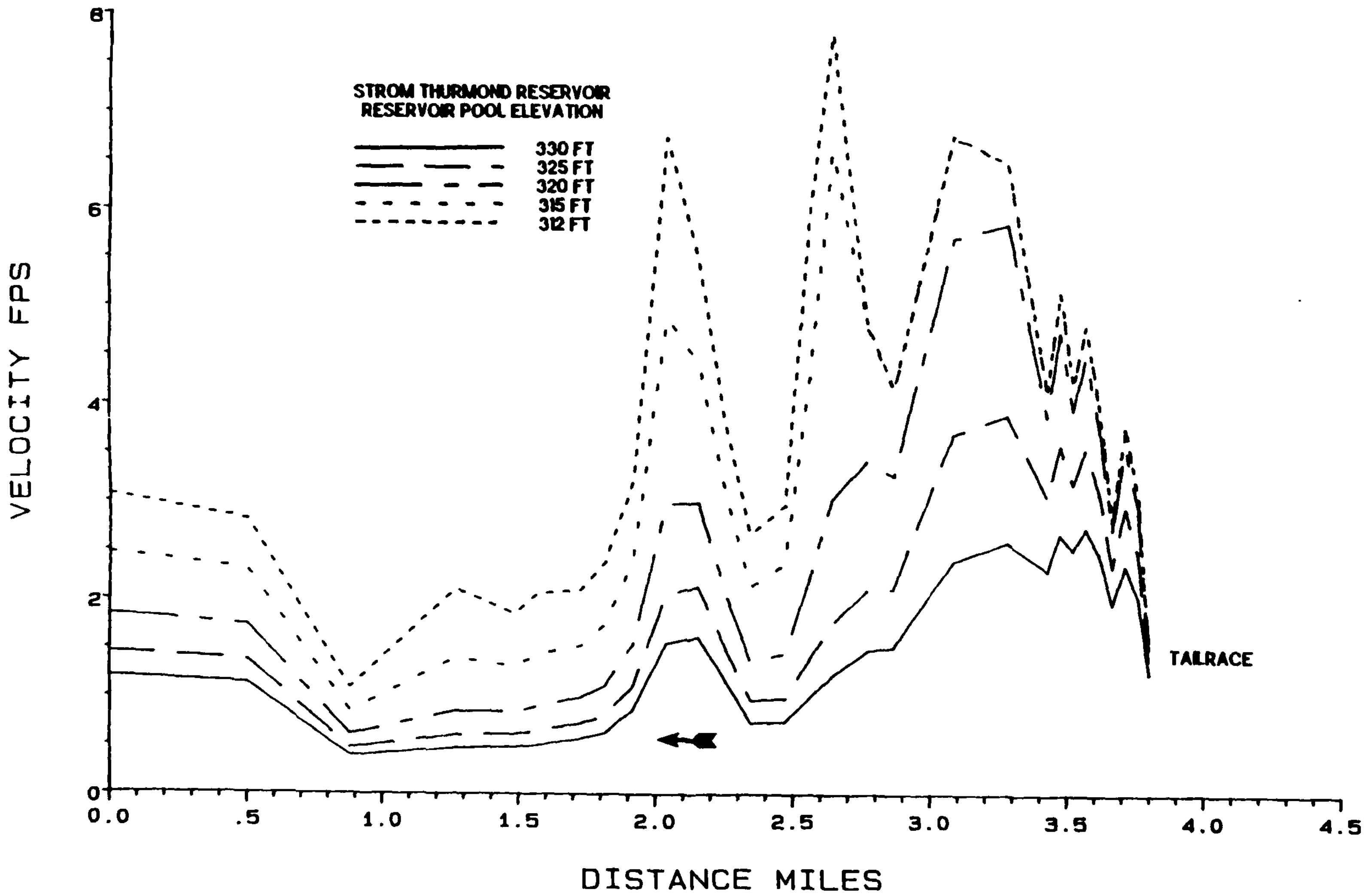


Figure 34. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 310 ft (n = 0.03)

PART VI: CONCLUSIONS AND RECOMMENDATIONS

36. The following study findings are a result of the the field study and numerical model investigation of capacity pumpback and generation flows from Richard B. Russell Dam in the headwater regions of JSTR. Backwater effects during capacity generation will raise tailwater stages and reduce the effective head available for hydropower generation when JSTR levels drop below elevation 325 ft for the existing channel configuration. There is a high probability that some bed material will scour during this flow event. The extent of sediment transport during capacity generation flows was outside the scope of this study. It is recommended that the sediment transport characteristics in the headwaters of JSTR be further investigated because of implications with the proposed dredging plans and subsequent operation of pumped storage. The potential may exist to promote significant scour in portions of the headwater regions of JSTR, thereby reducing the extent of or eliminating the need for dredging.

37. The existing bed configuration will significantly influence flow conditions during capacity pumpback events. When JSTR levels drop below elevation 320 ft, the tailrace will begin to experience significant draw down. As the JSTR level approaches minimum pool, the location of flow control will change resulting in a continuous depletion of water in the tailwater region. The resultant drawdown may proceed to the point of impacting pumpback operations. The target velocity of 2 fps is reached when lake levels fall below elevation 325 ft. These preliminary results will need to be reevaluated if significant bed movement takes place during project operation.

38. Improvements in the hydrodynamic properties of JSTR headwaters can be achieved through channel excavation. A trapezoidal channel with a bottom width of 800 ft and an invert elevation of 298 ft, connecting Transects L750 and L6500, will reduce the maximum pumpback velocities to 2 fps during minimum pool conditions. This channel configuration would generally eliminate both the setup and draw down of stages in the tailrace region during capacity generation and pumpback. Constructing this channel improvement would require 3.3 million cubic yards of material to be removed from the study area. The alternative channel configurations explored in this study require less excavation but result in higher channel velocities.

APPENDIX A: CHANNEL CROSS SECTIONS

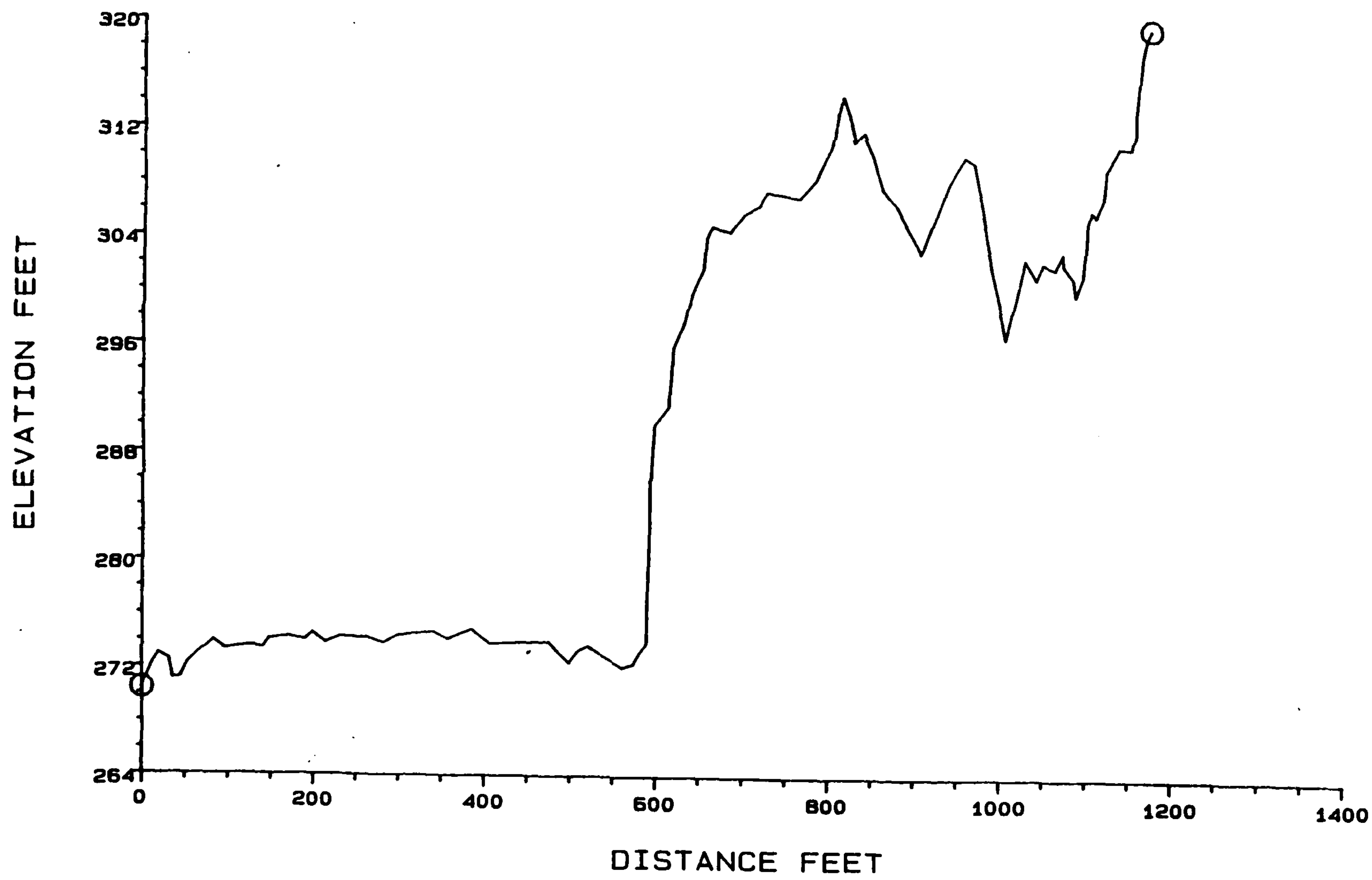


Figure A1. Channel cross section L300

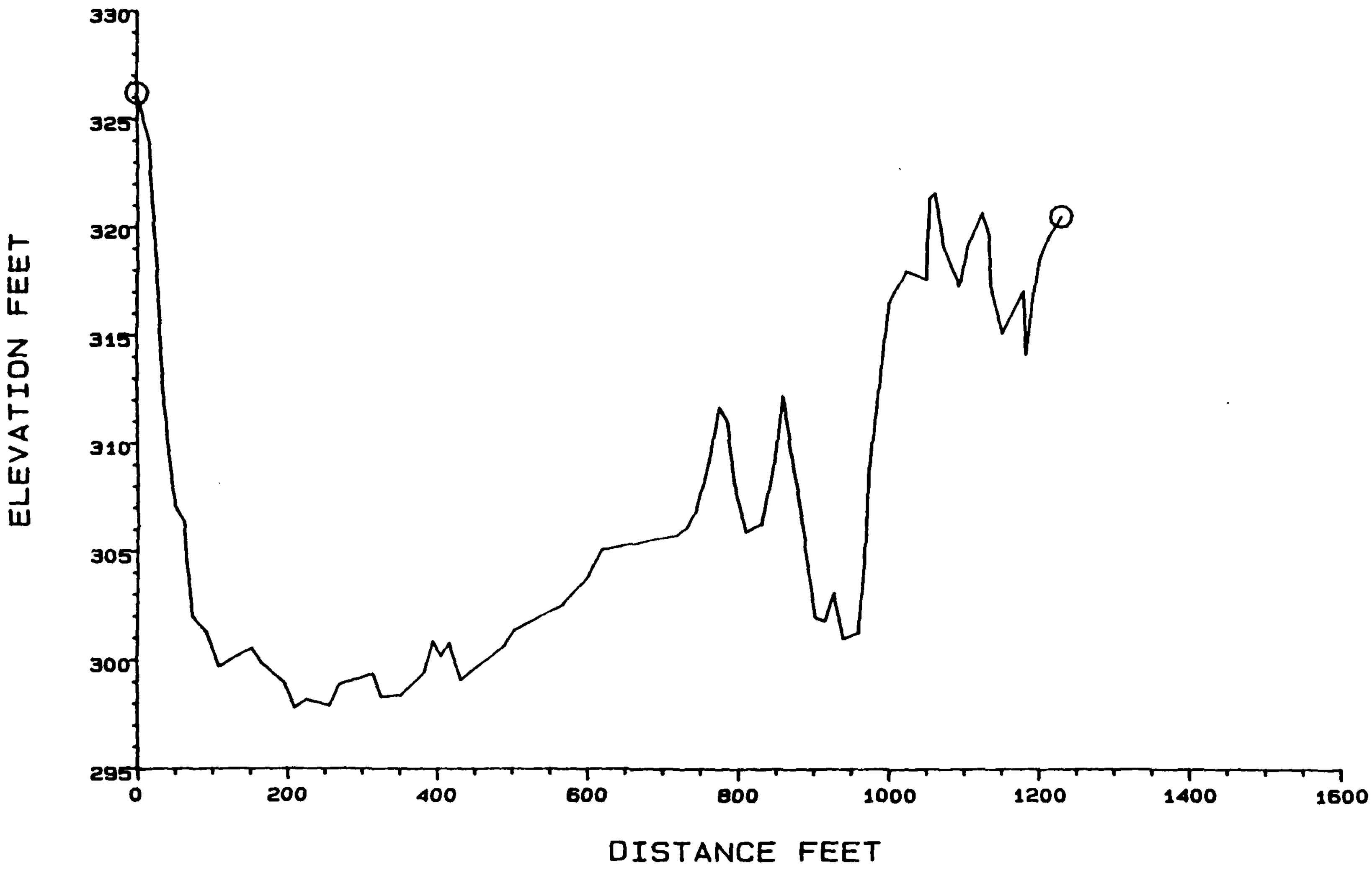


Figure A2. Channel cross section L500

Figure A2. Channel cross section L500

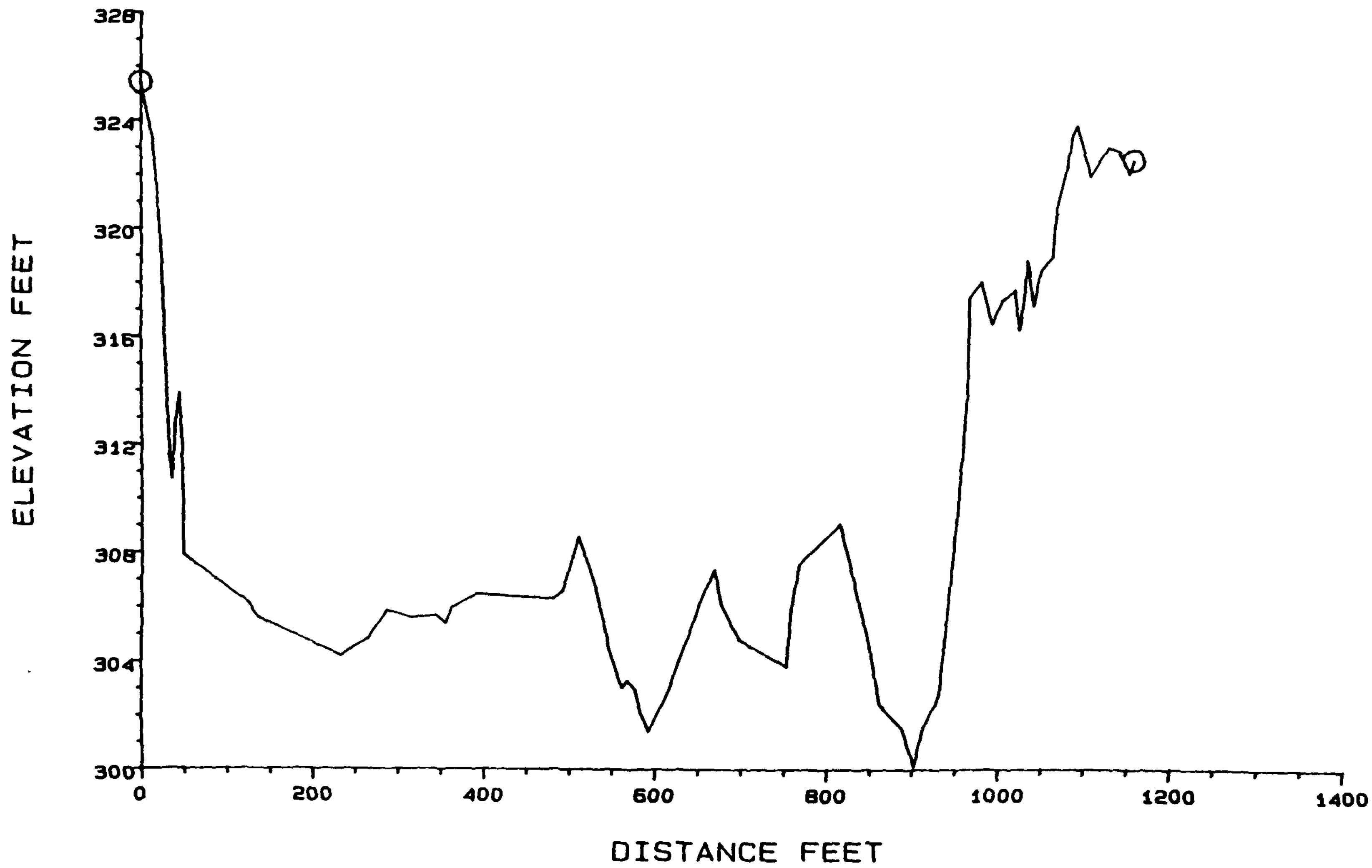


Figure A3. Channel cross section L750

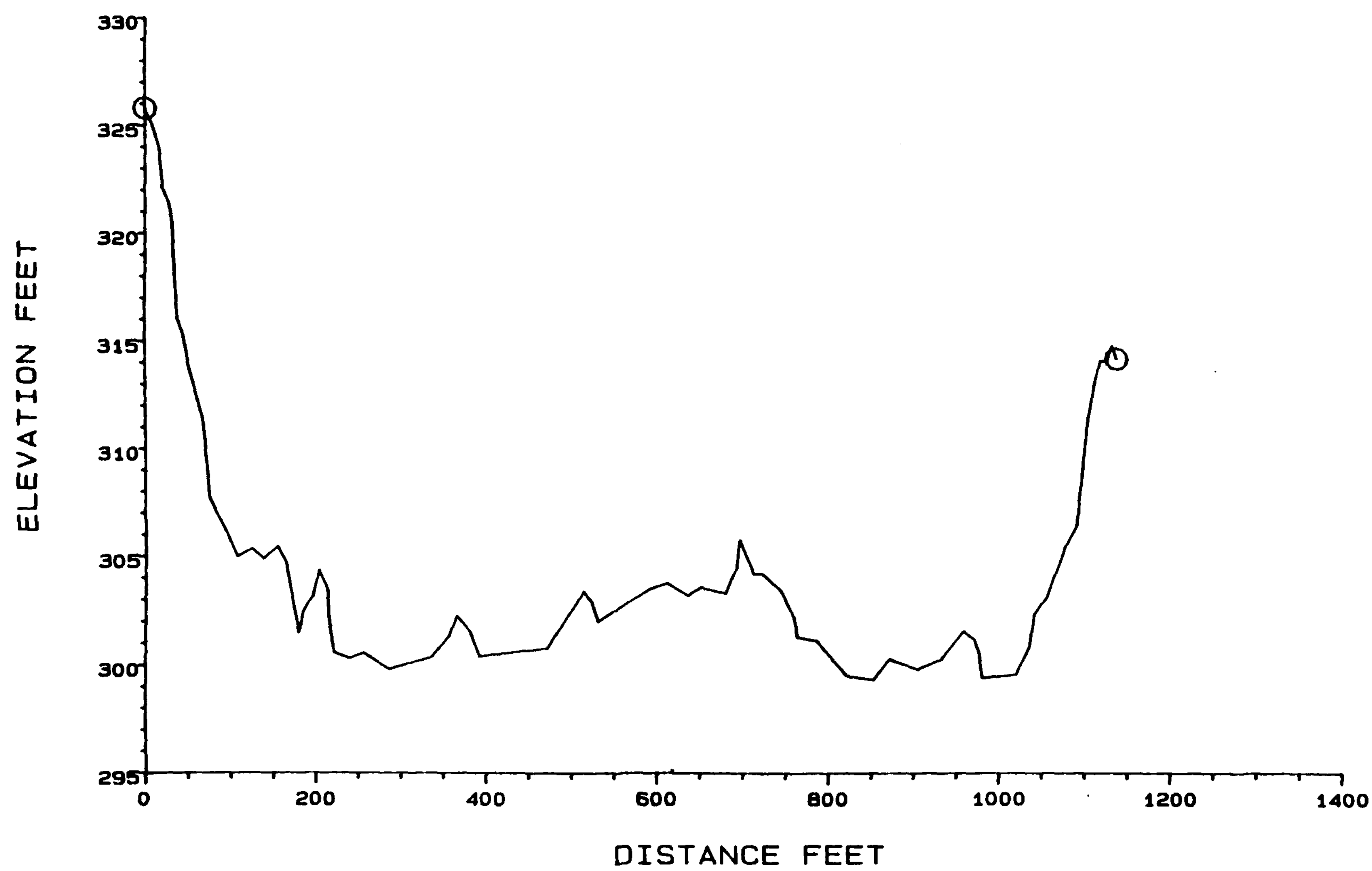


Figure A4. Channel cross section L1000

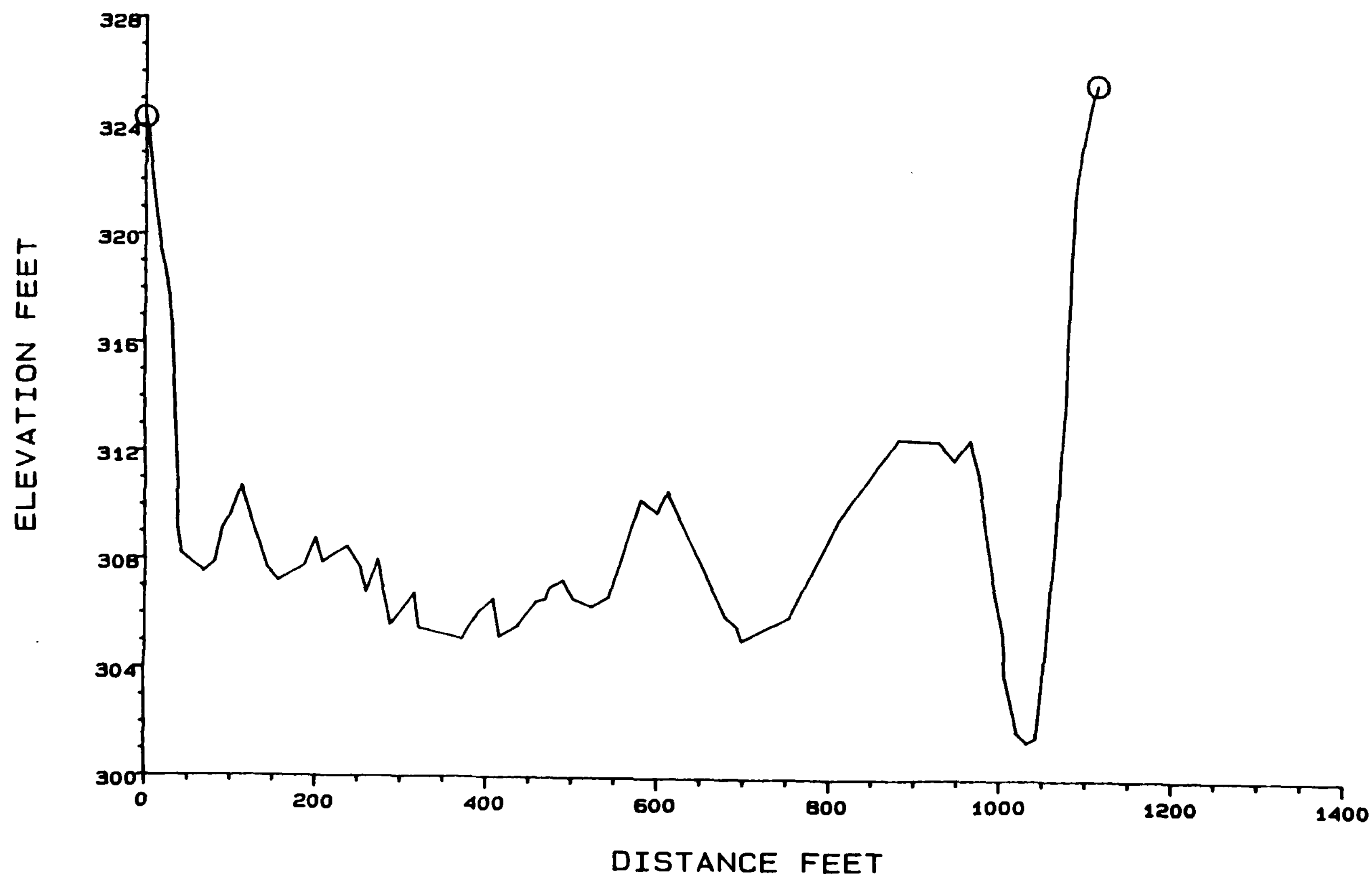


Figure A5. Channel cross section L1250

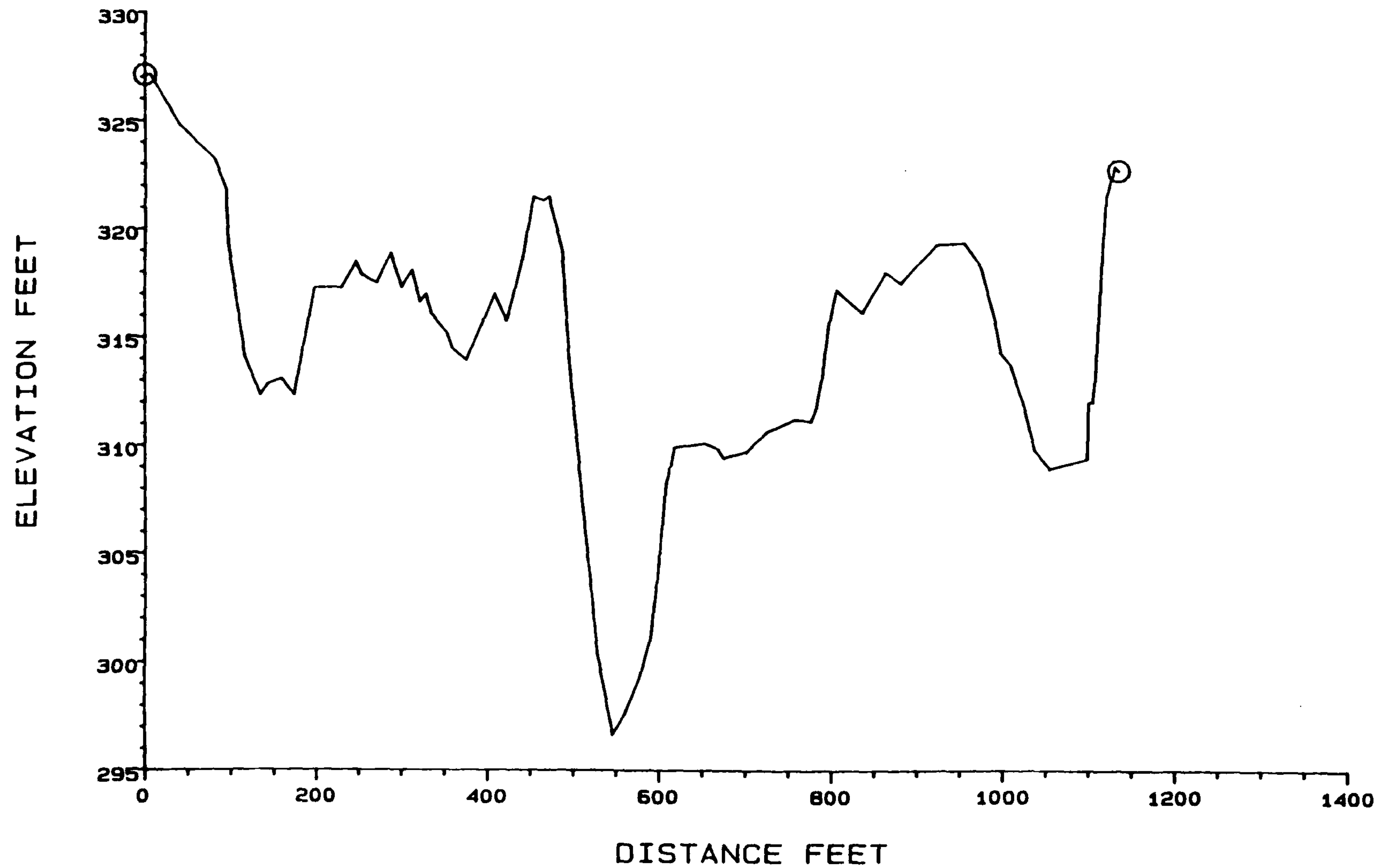


Figure A6. Channel cross section L1500

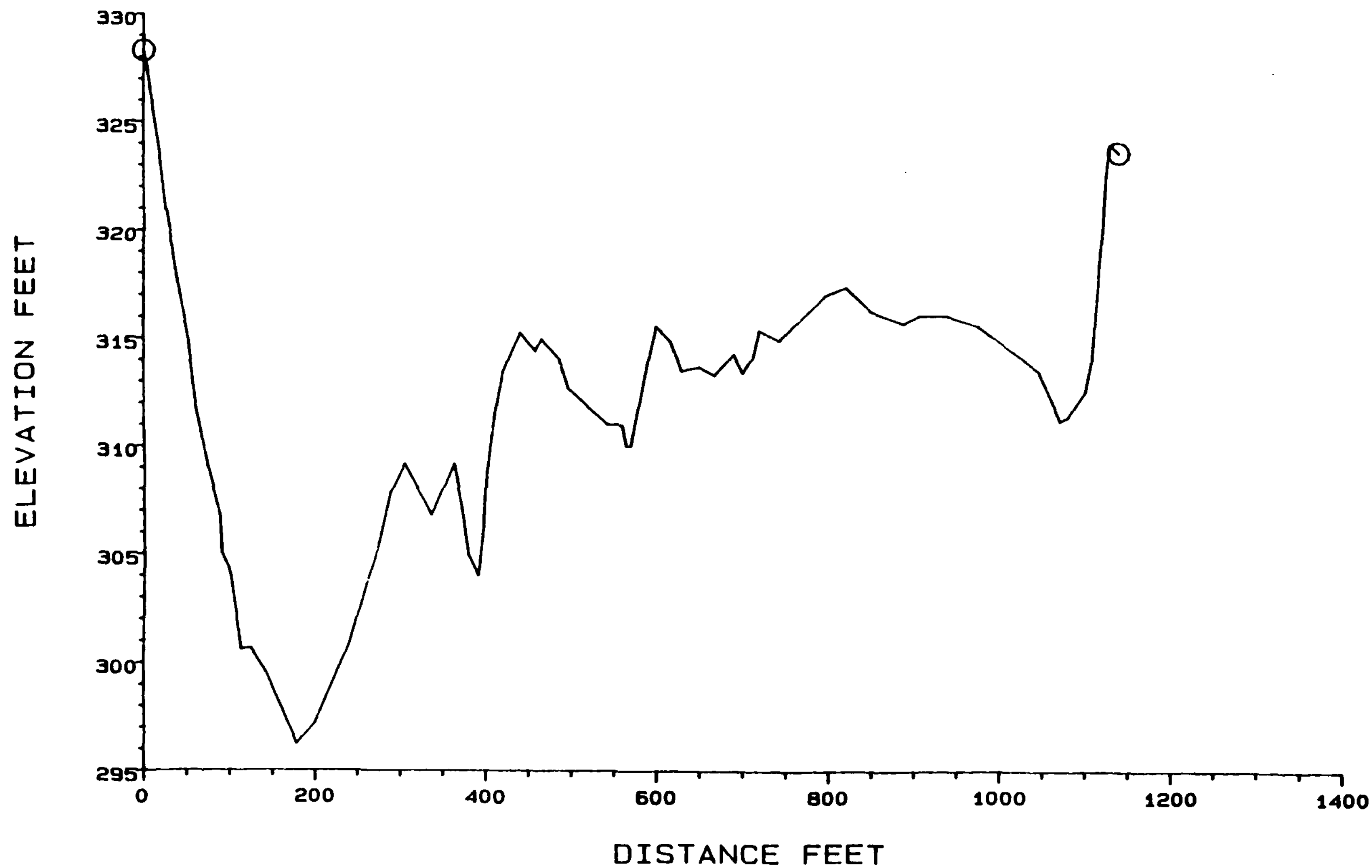


Figure A7. Channel cross section L1750

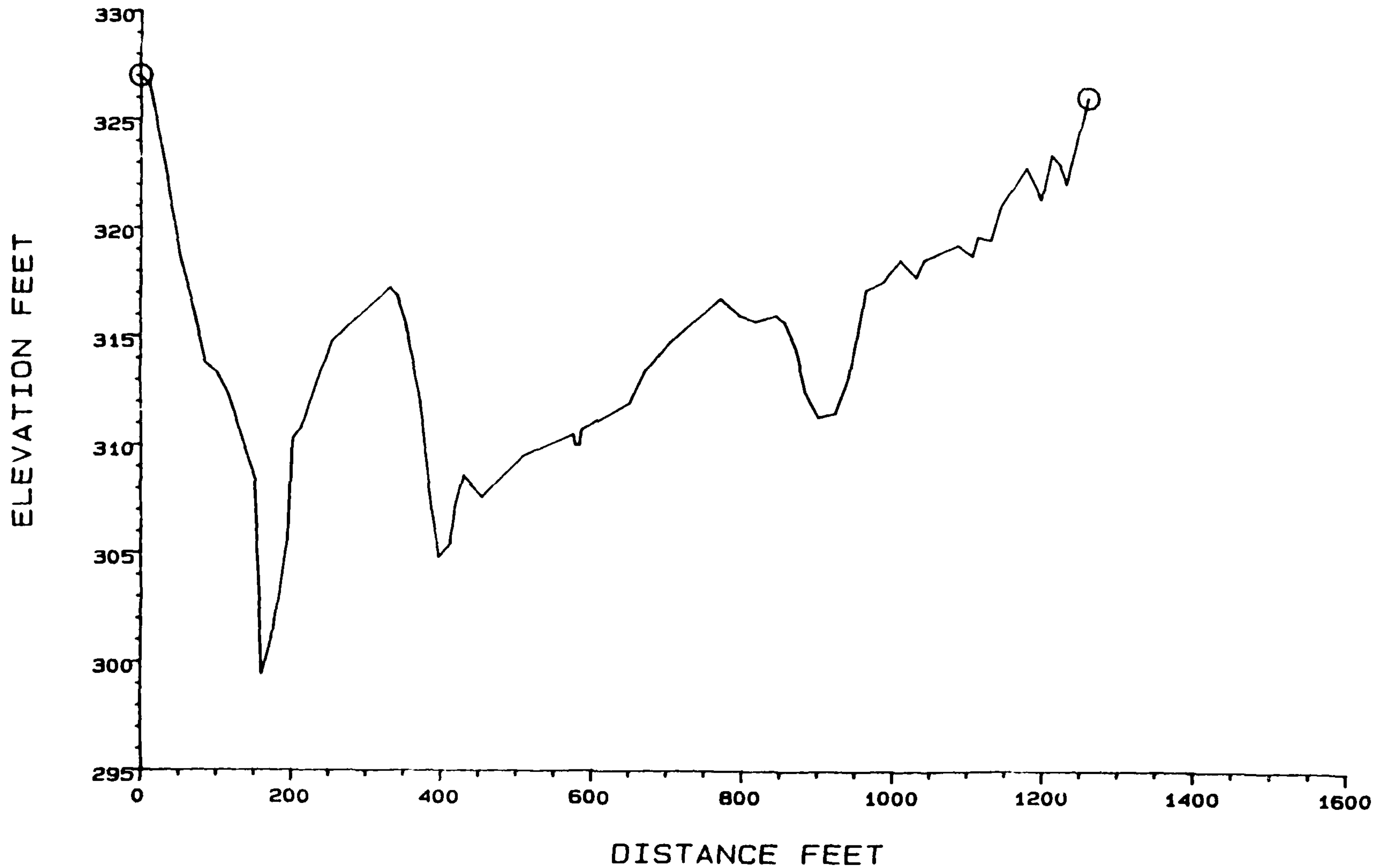


Figure A8. Channel cross section L2000

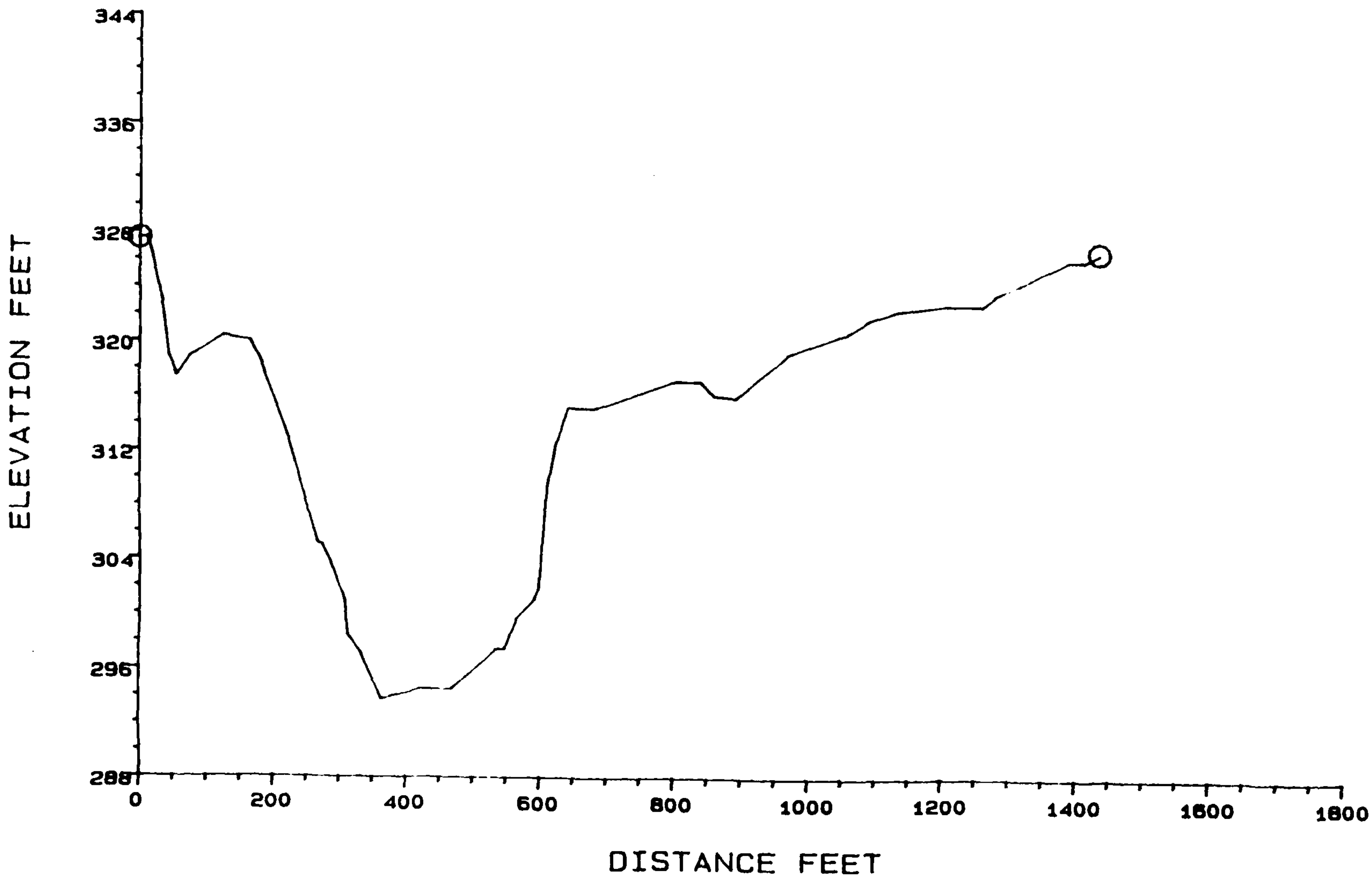


Figure A9. Channel cross section L2250

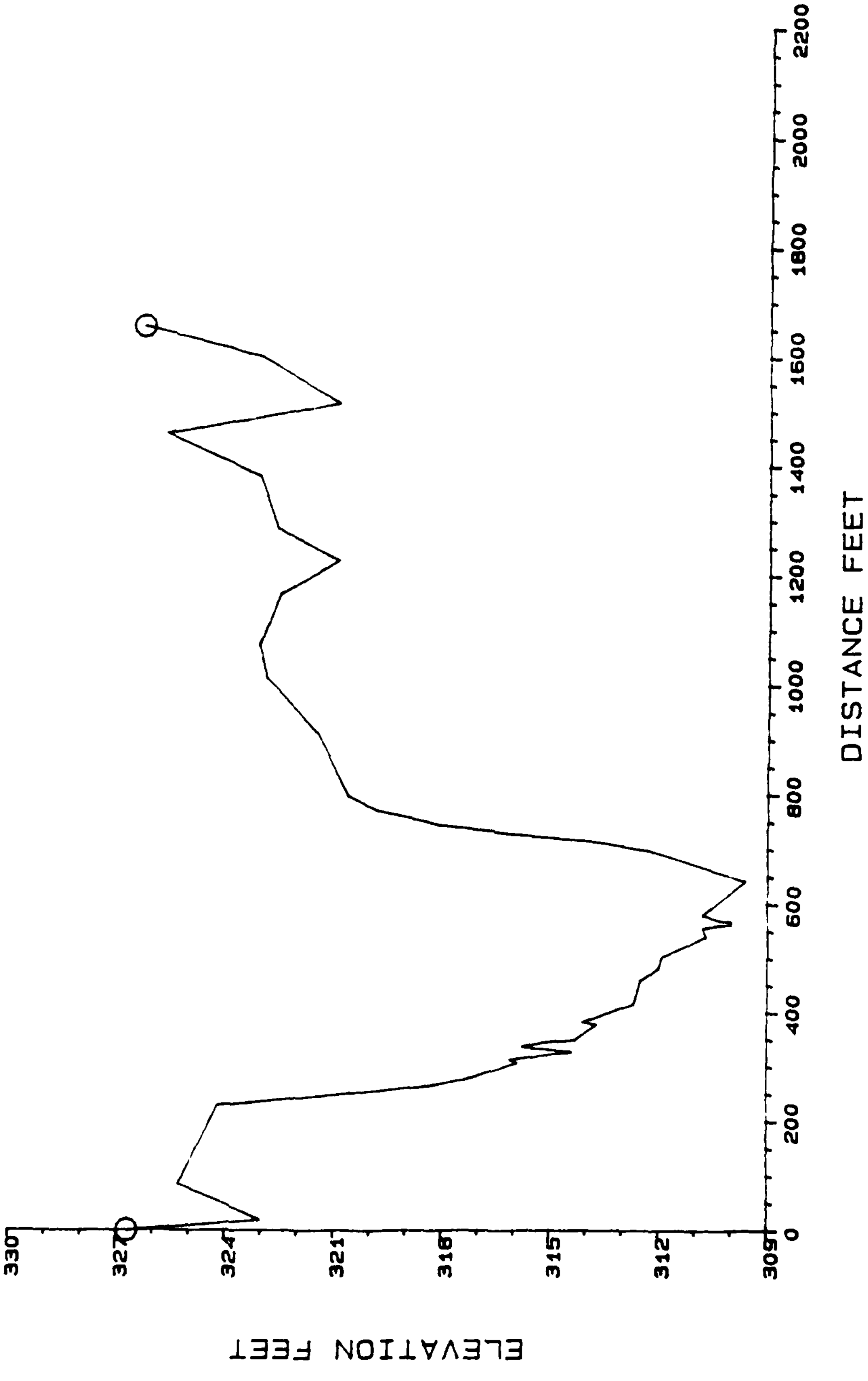


Figure A10. Channel cross section L3000

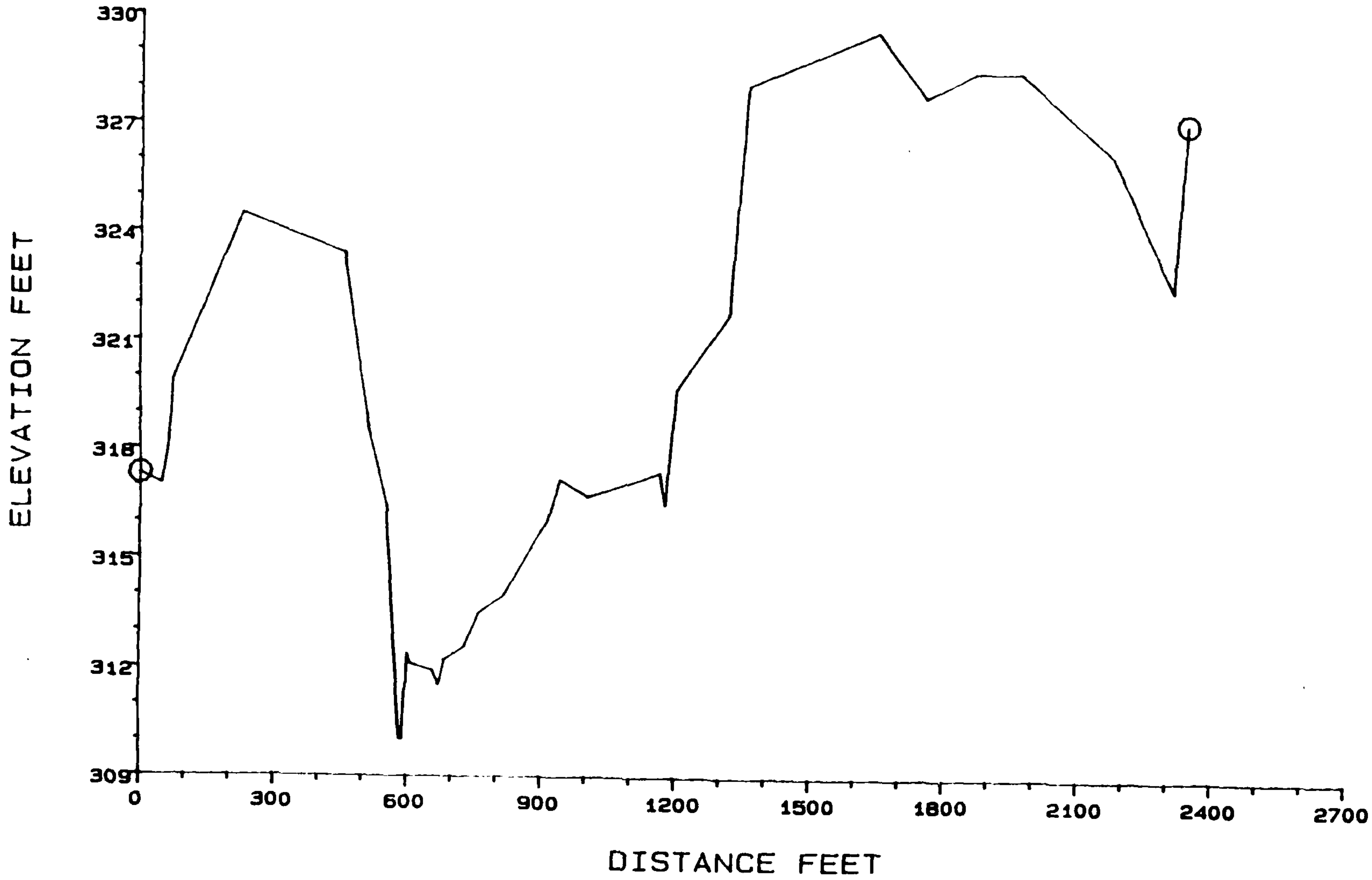


Figure A11. Channel cross section L4000

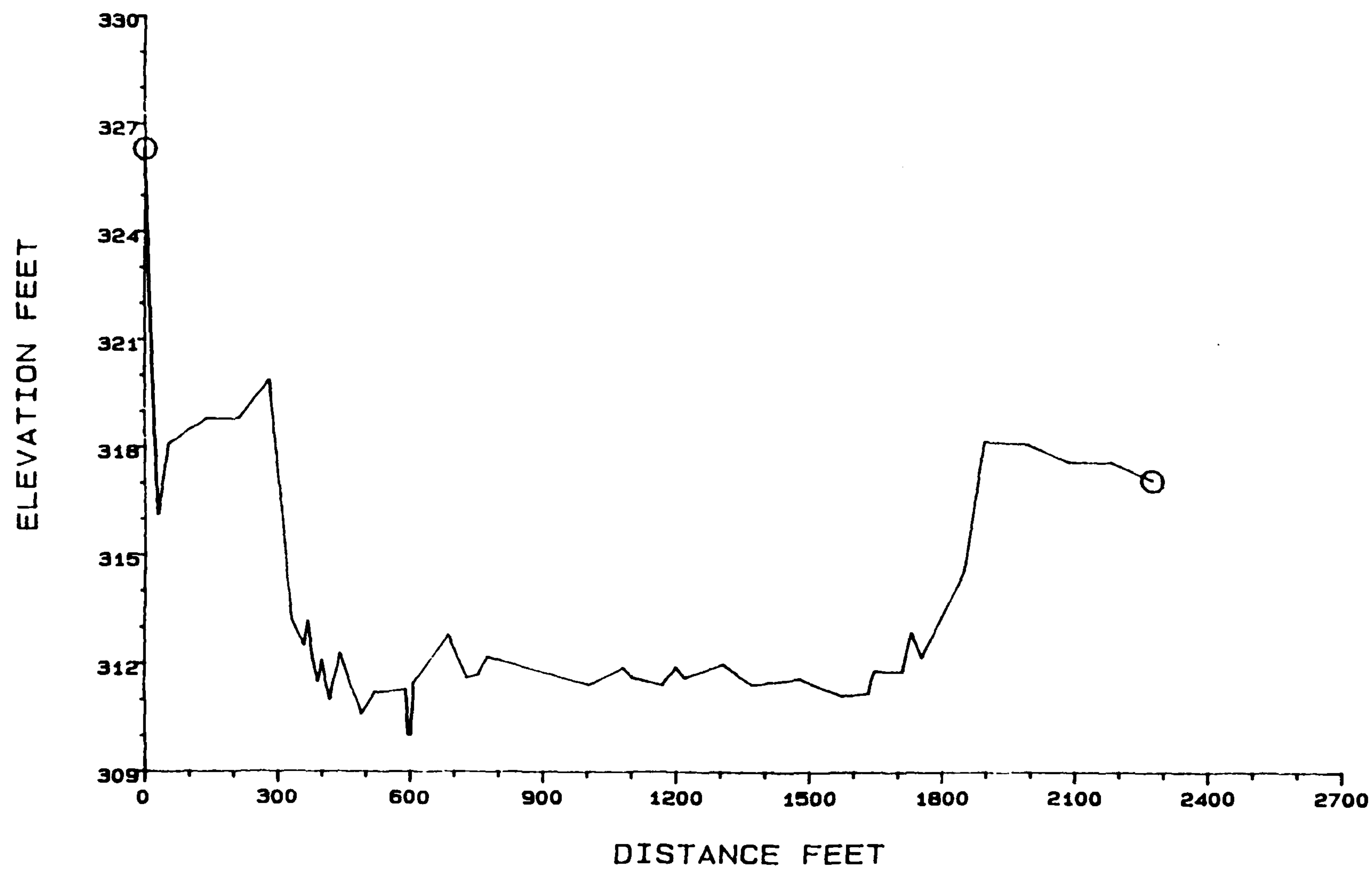


Figure A12. Channel cross section L5000

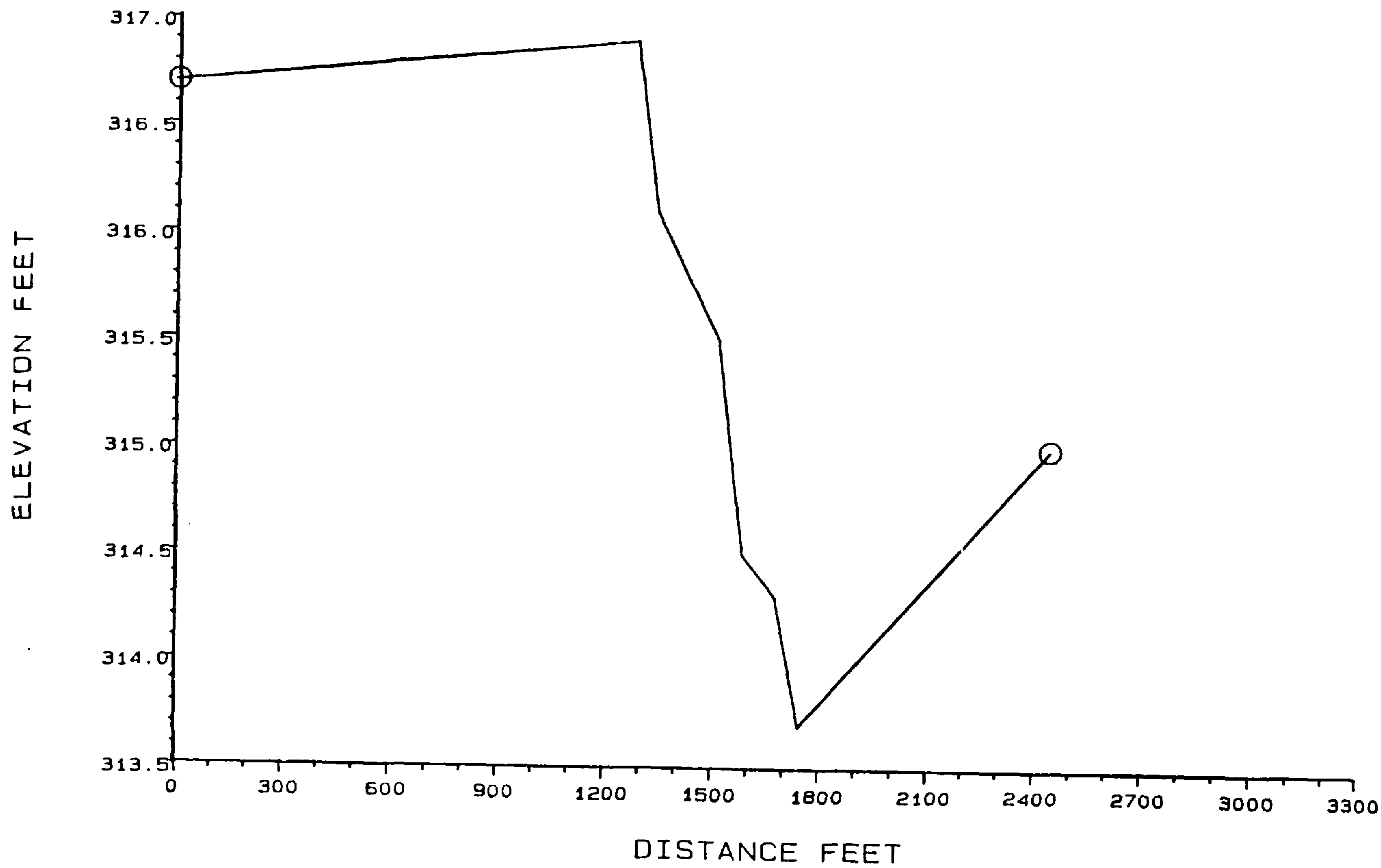


Figure A13. Channel cross section L5500

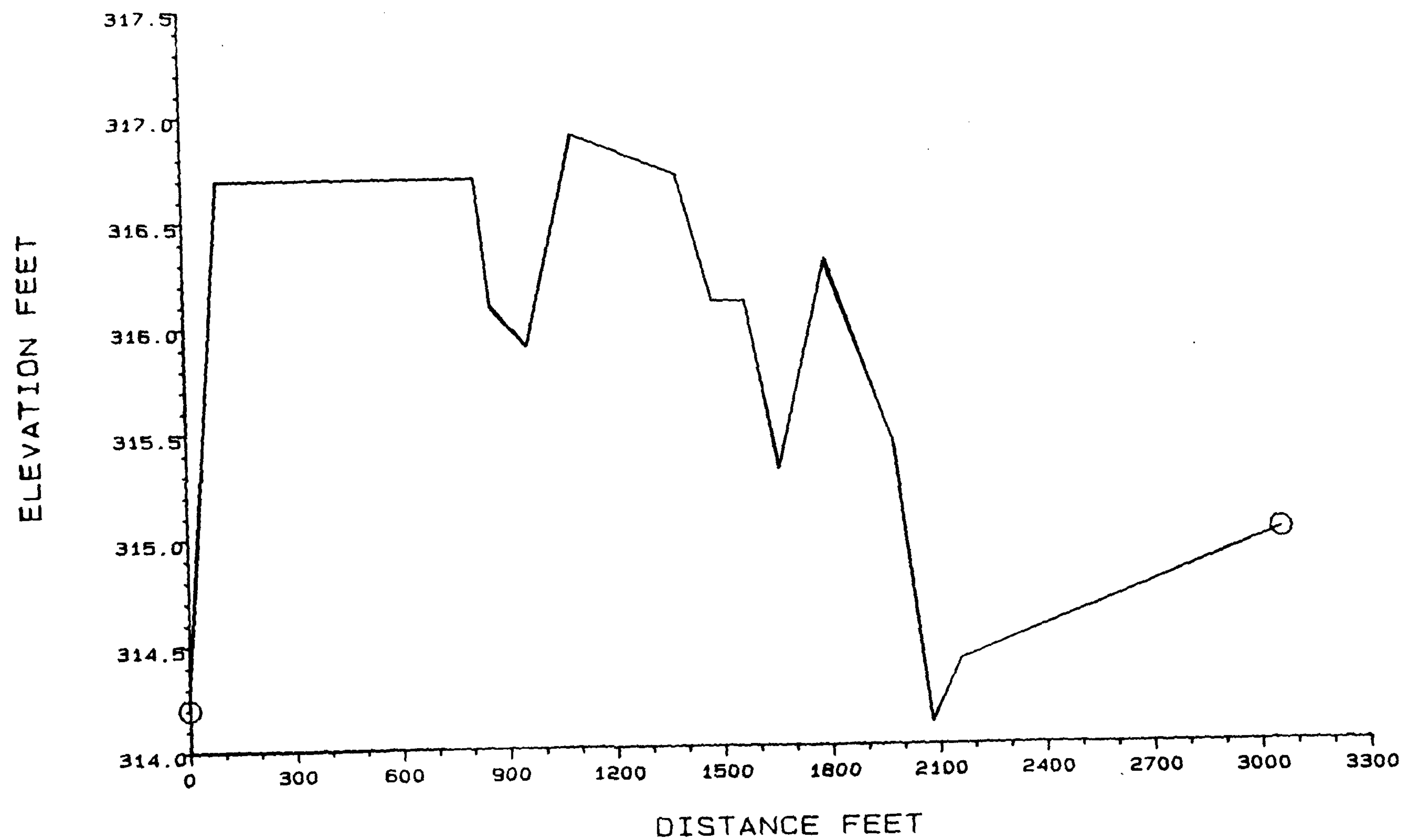


Figure A14. Channel cross section L6000

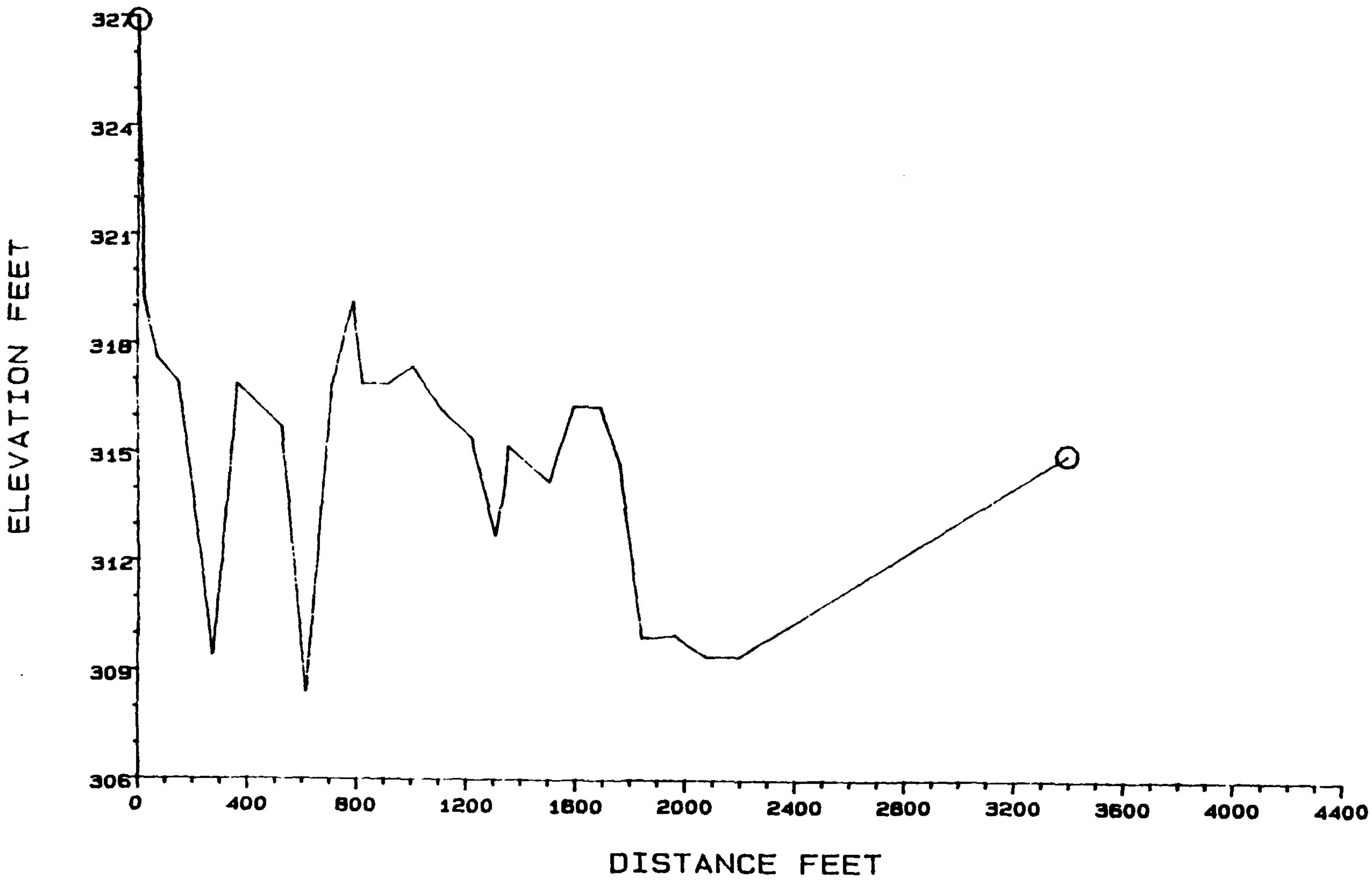


Figure A15. Channel cross section L6500

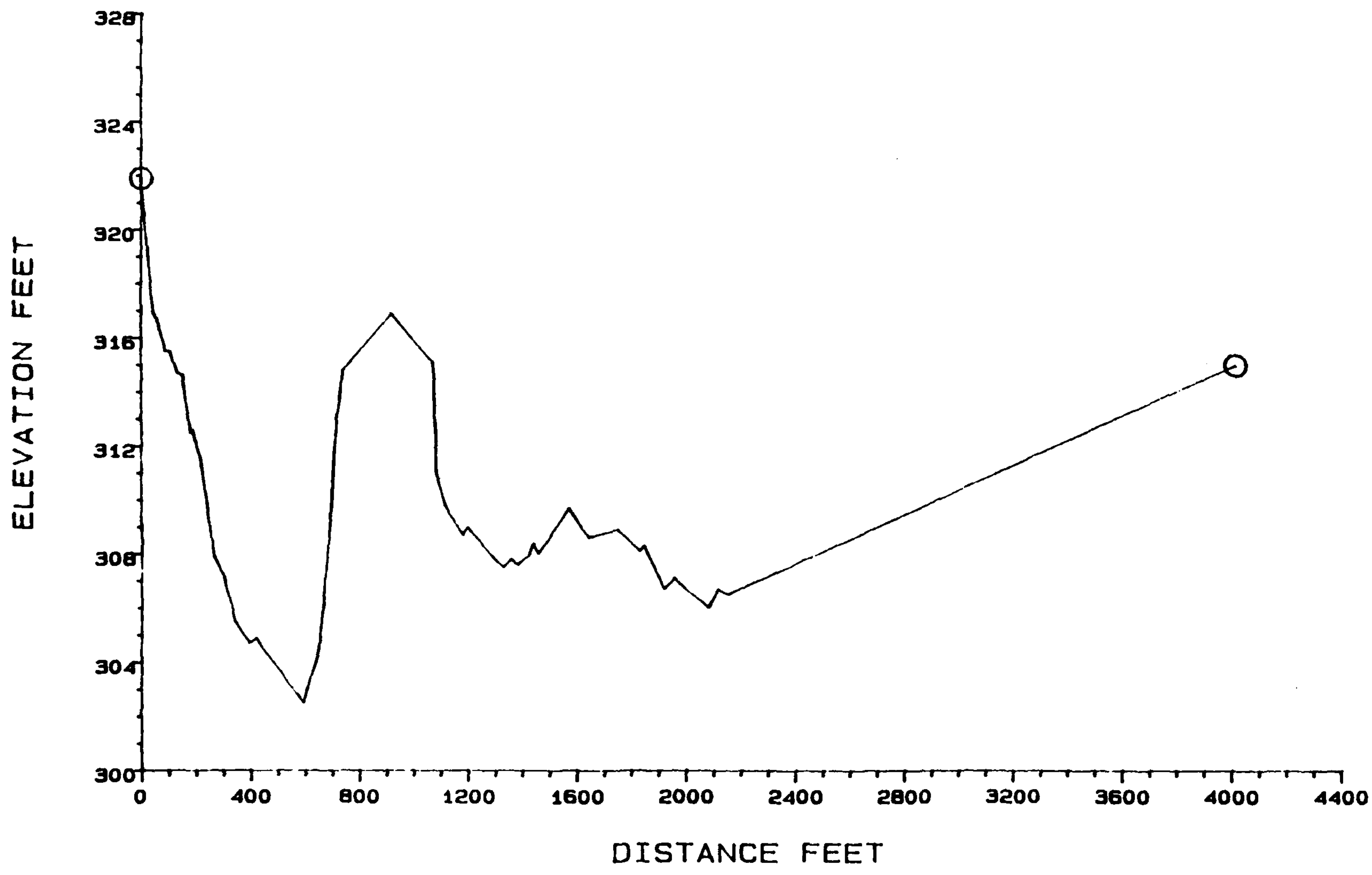


Figure A16. Channel cross section L7000

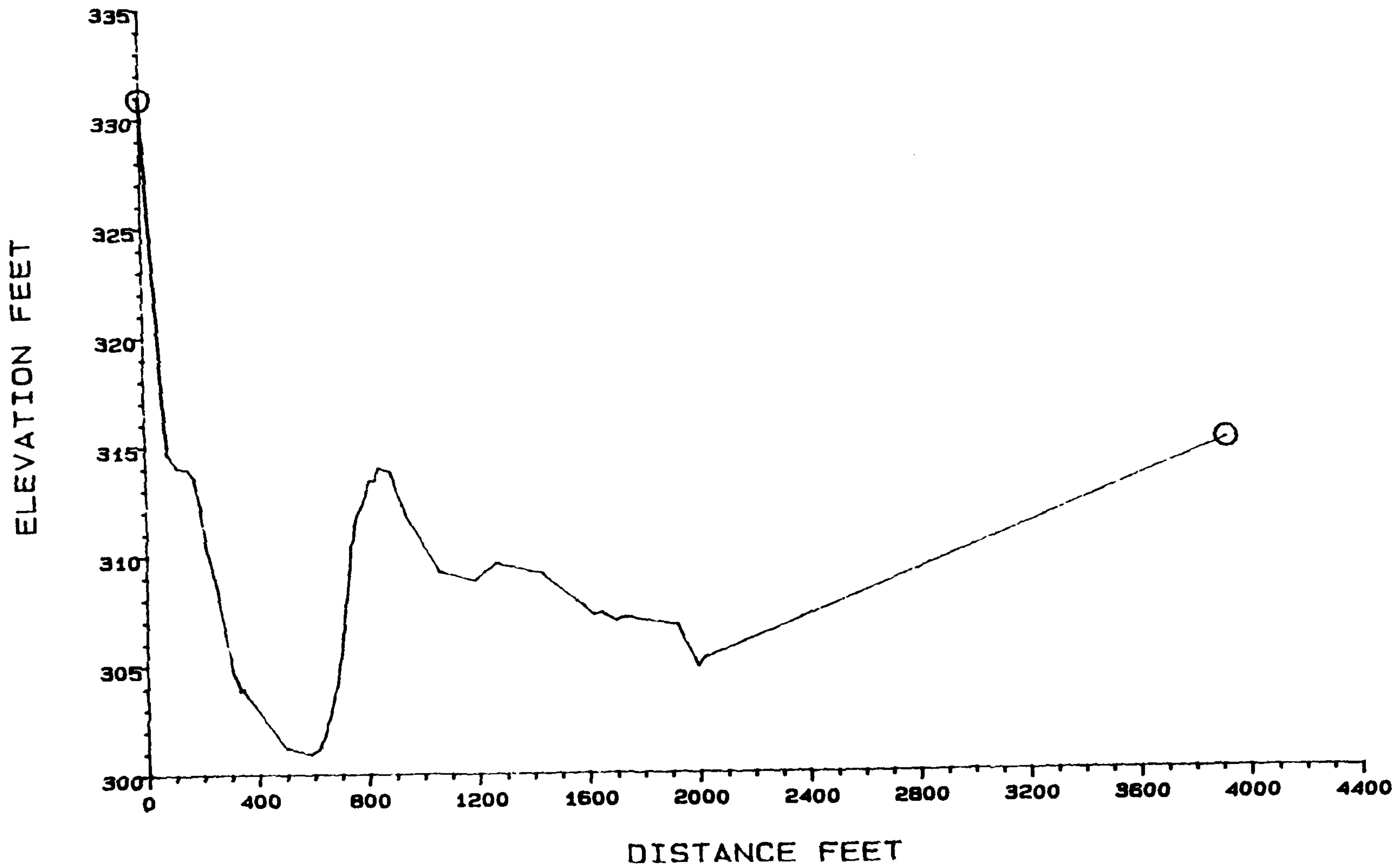


Figure A17. Channel cross section L7500

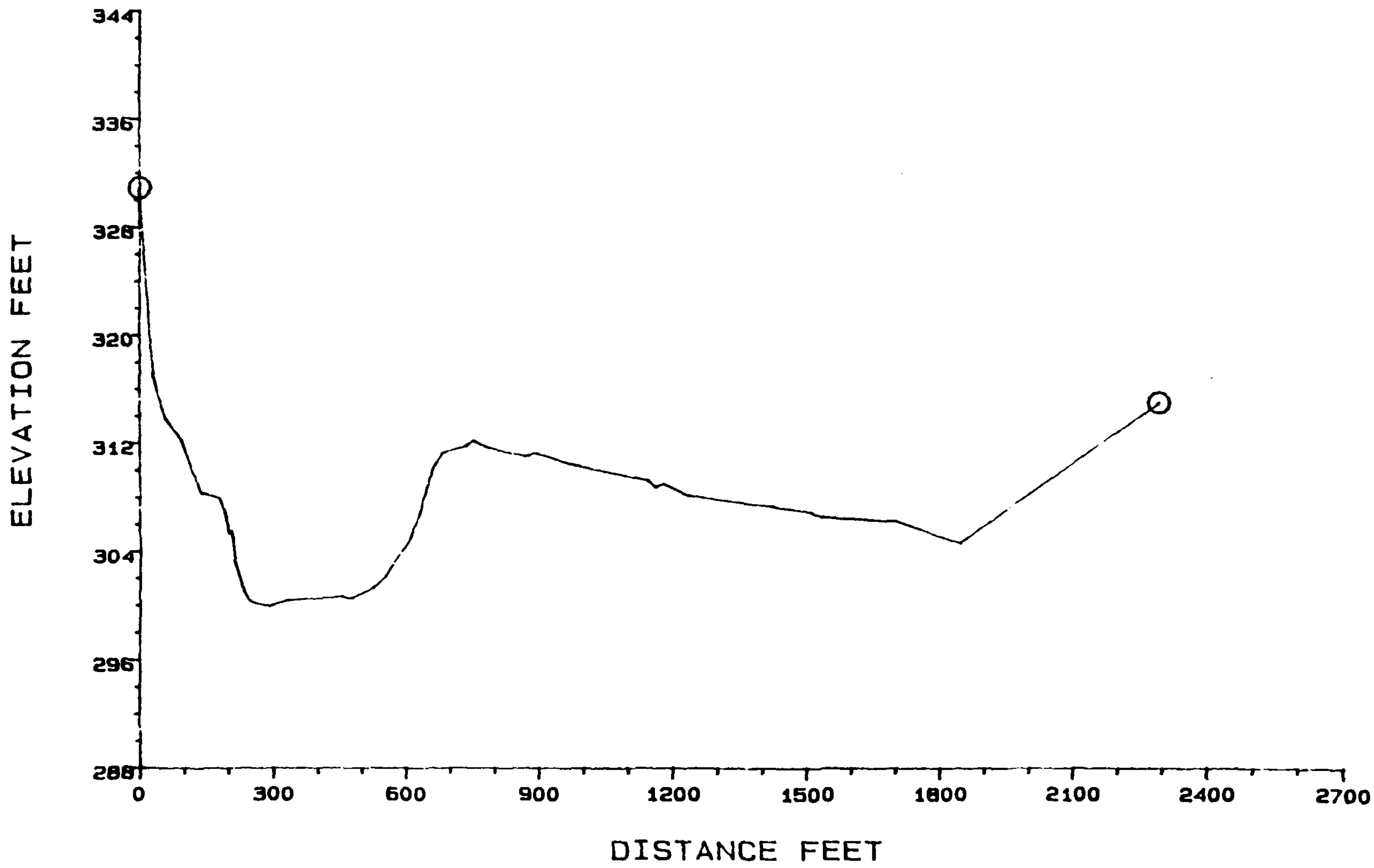


Figure A18. Channel cross section L8000

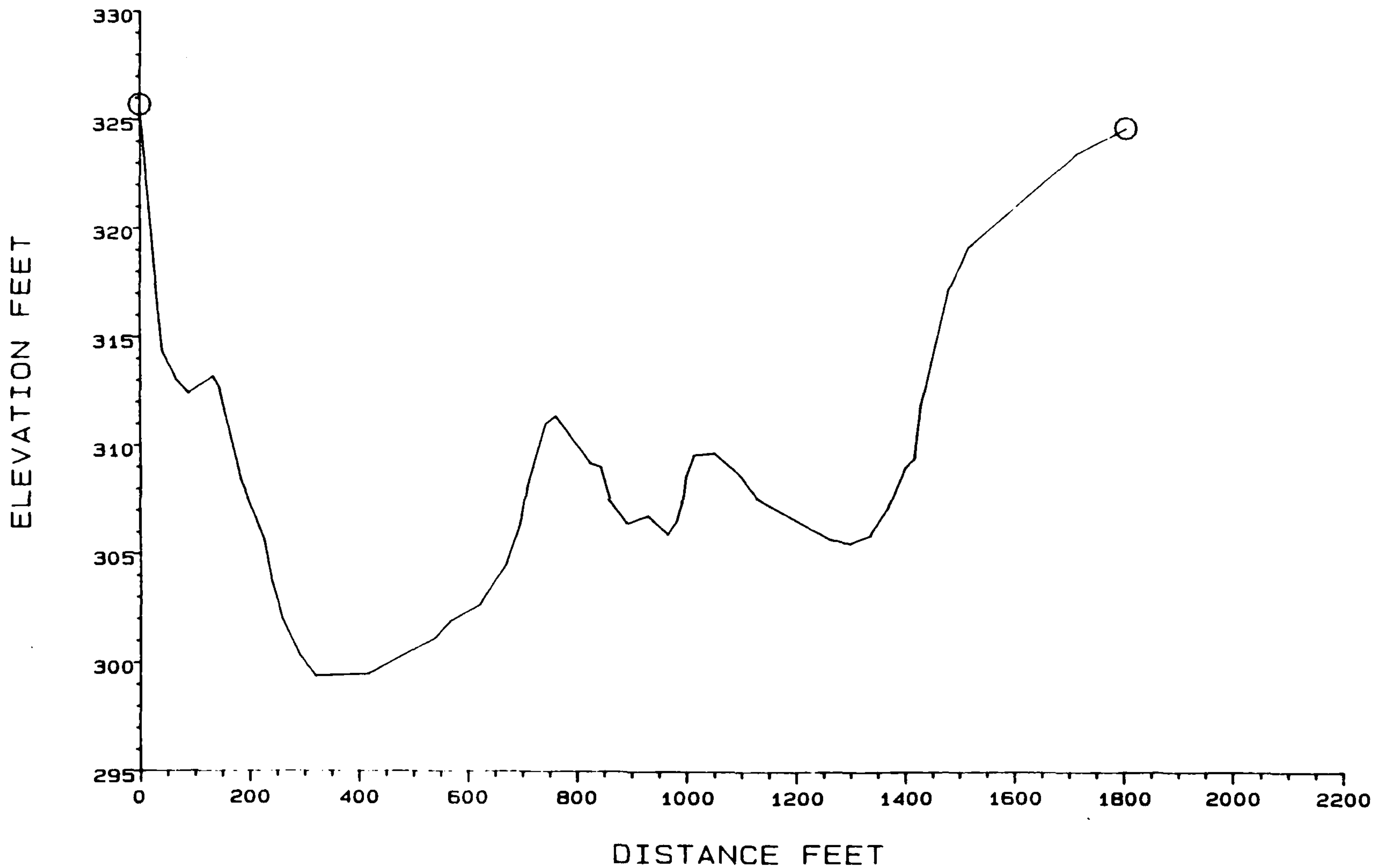


Figure A19. Channel cross section L8500

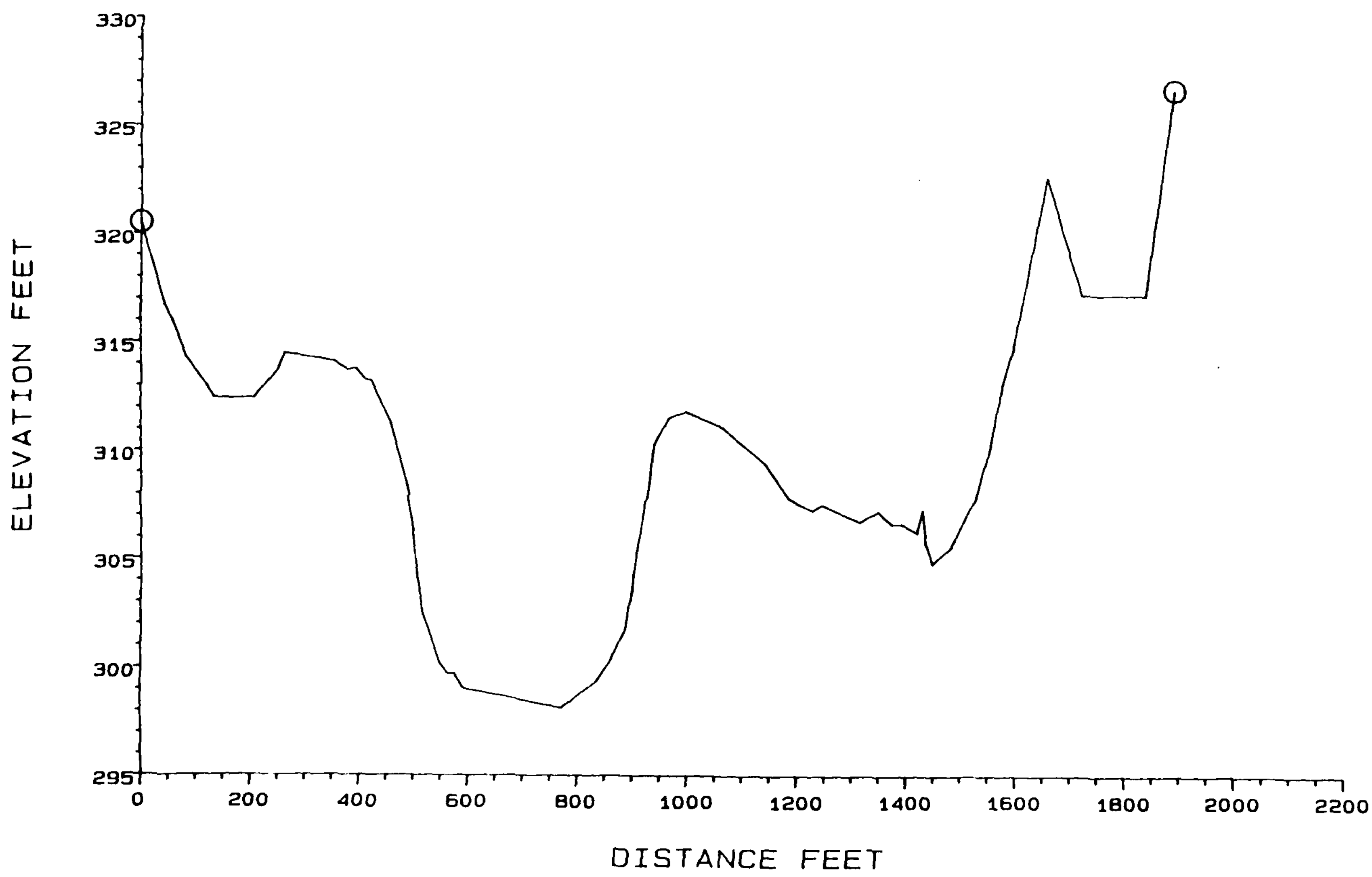


Figure A20. Channel cross section L9000

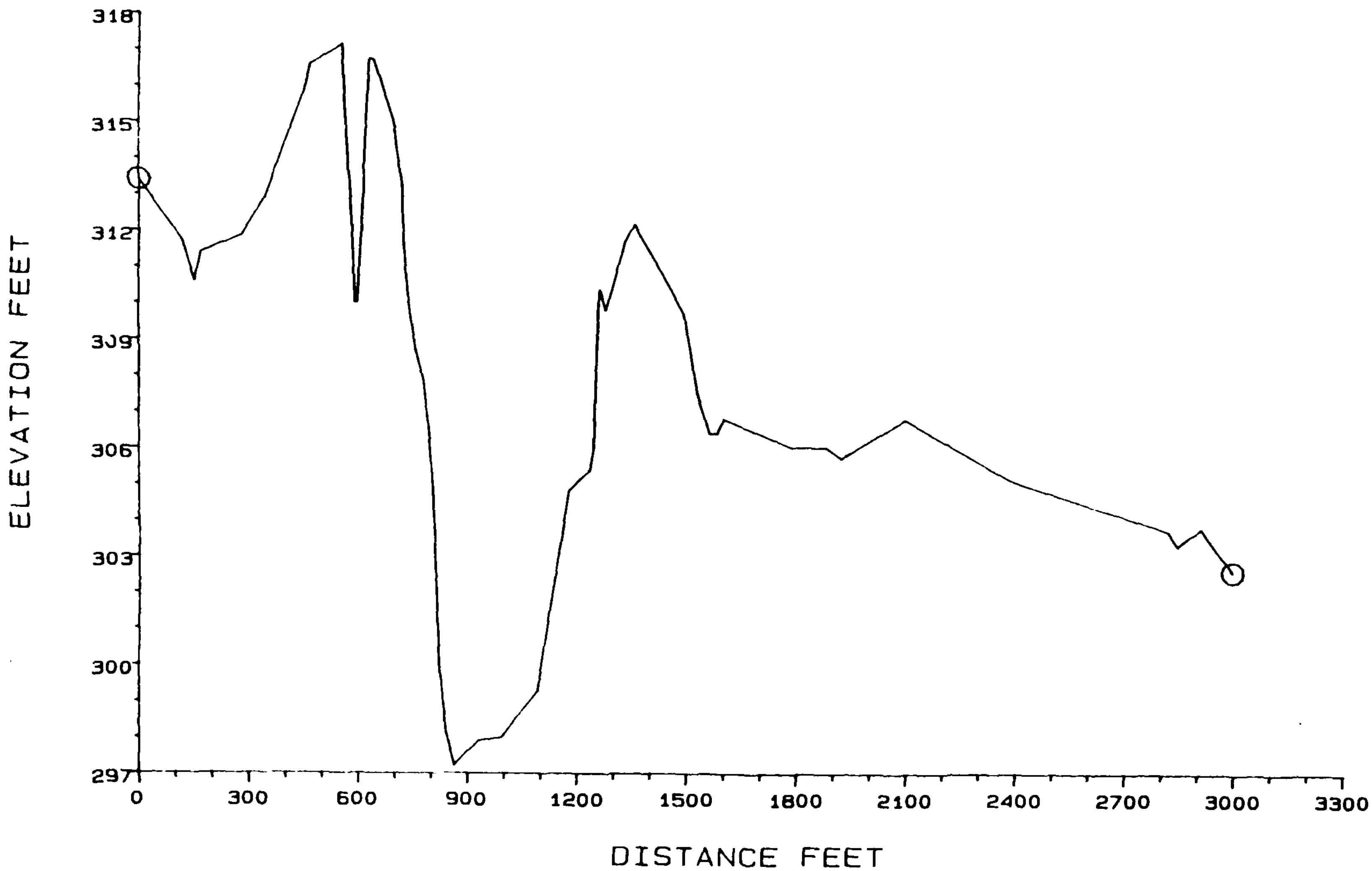


Figure A21. Channel cross section L9500

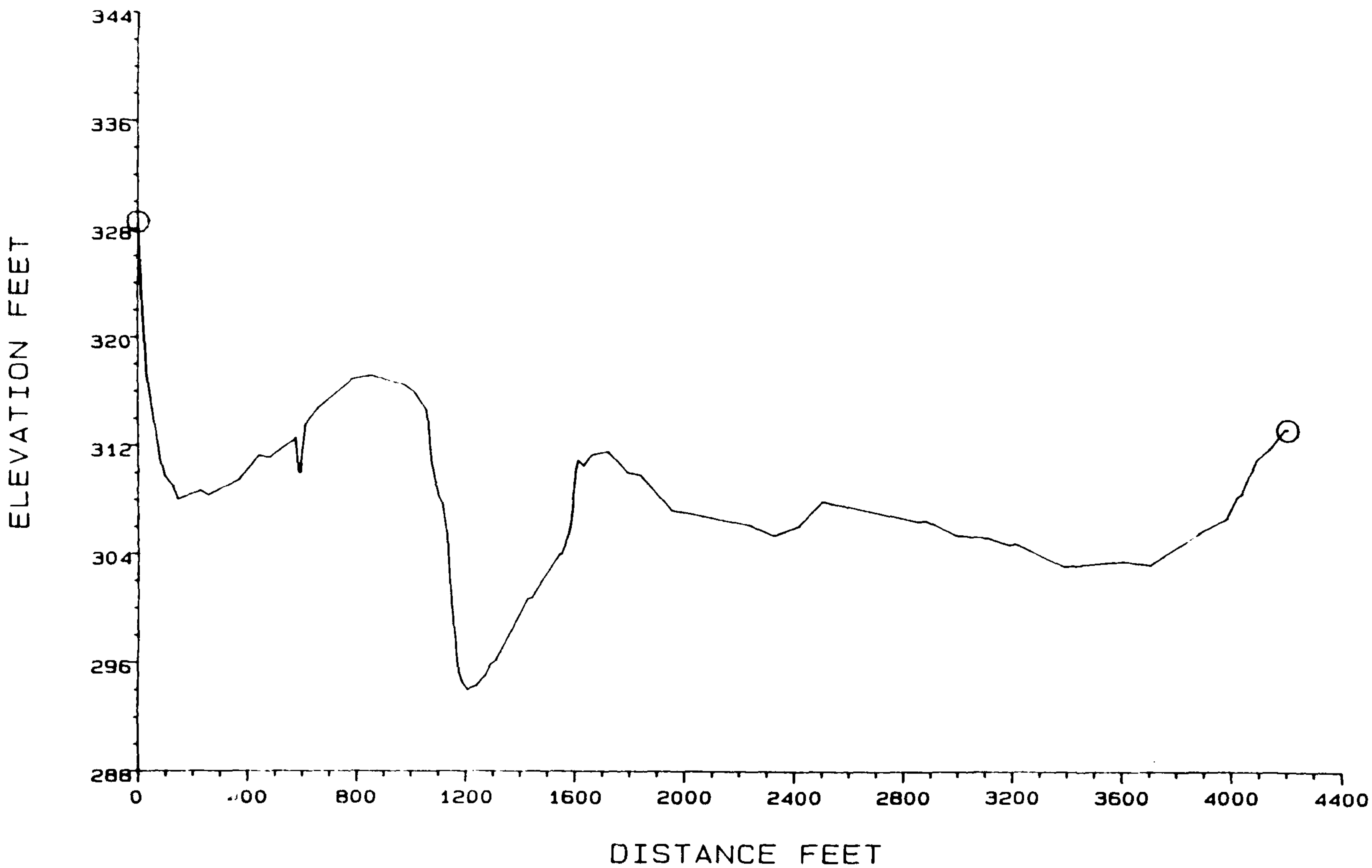


Figure A22. Channel cross section L10000

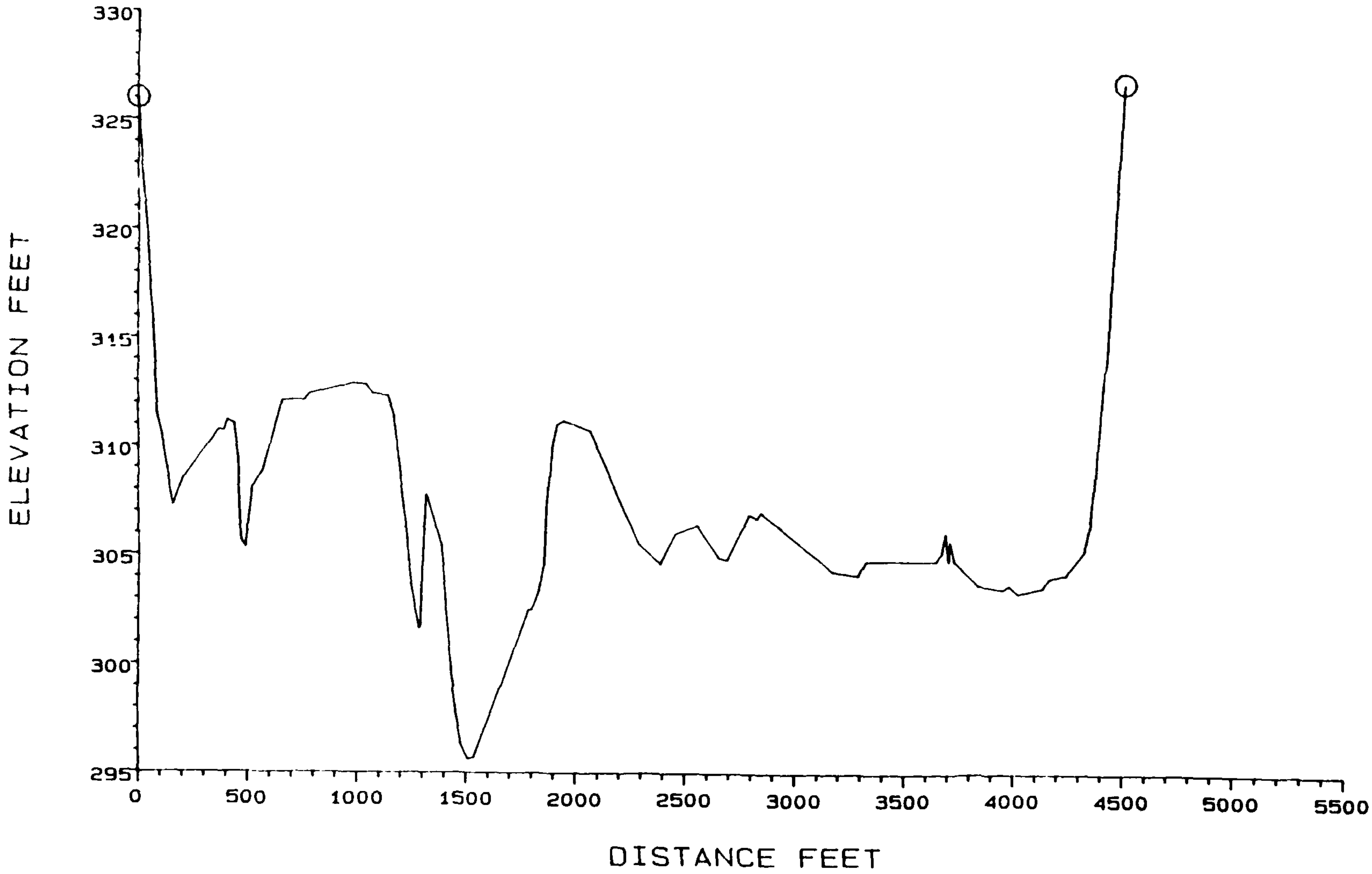


Figure A23. Channel cross section L10500

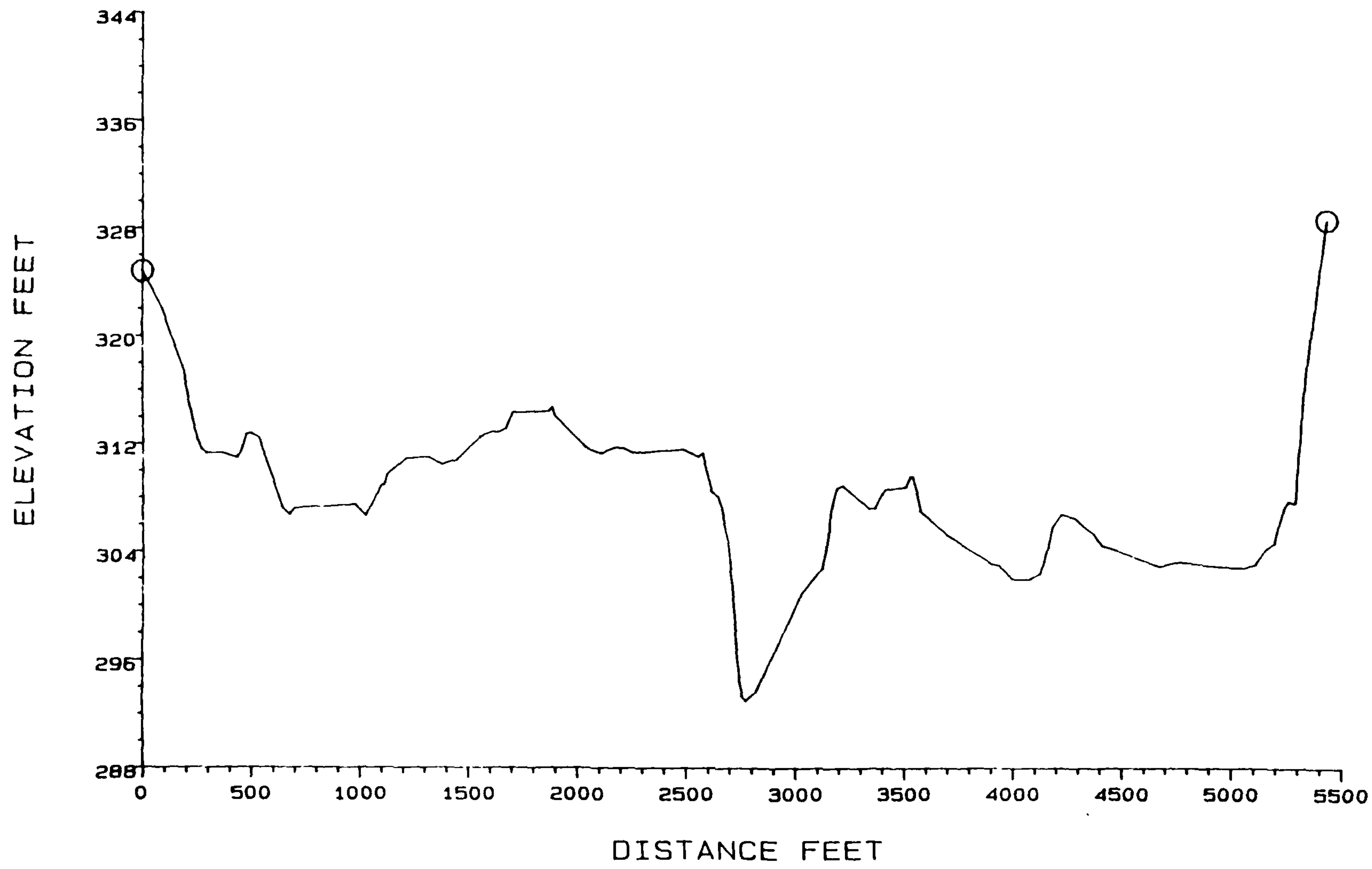


Figure A24. Channel cross section L11000

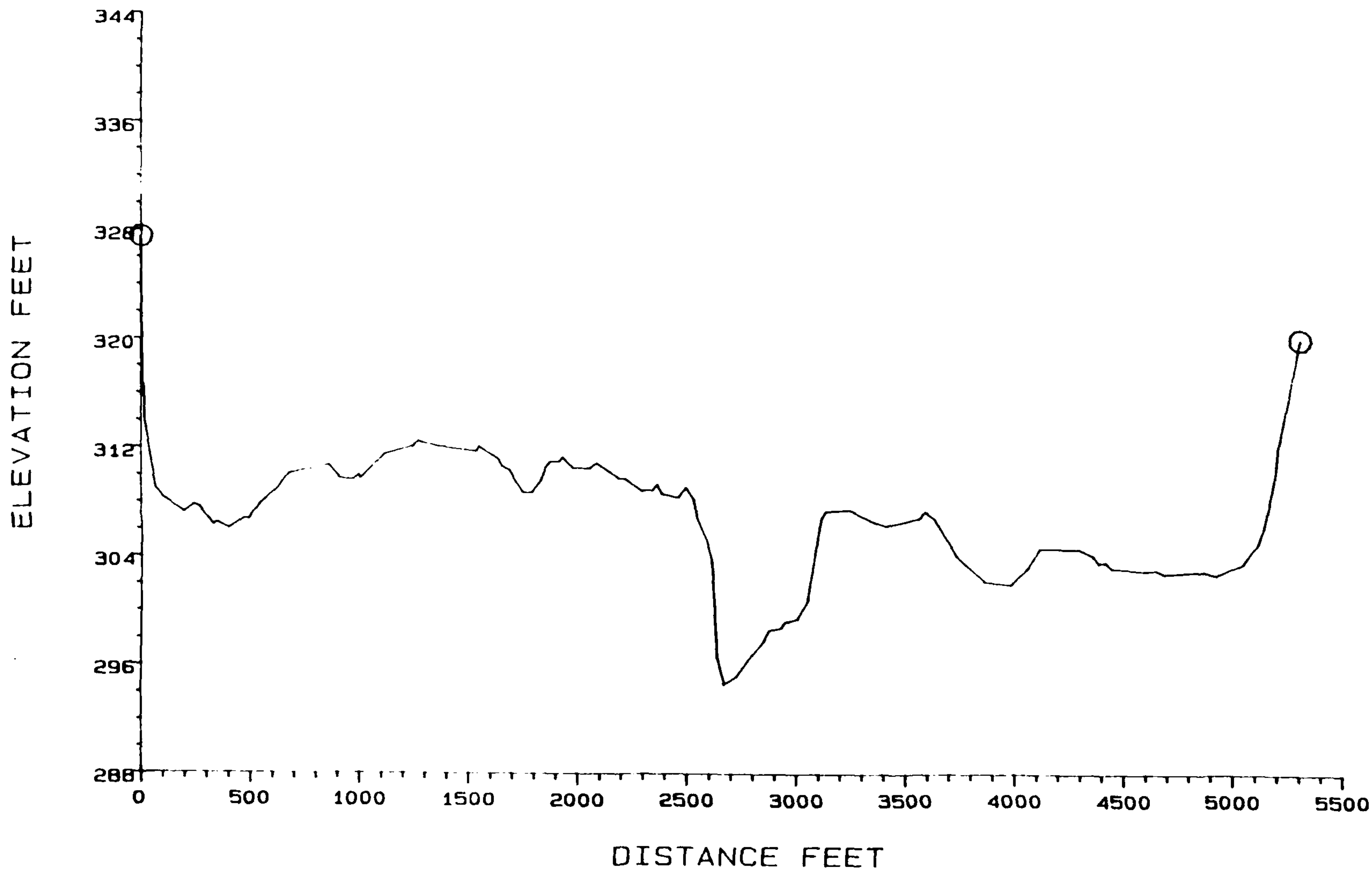


Figure A25. Channel cross section L11500

APPENDIX B: WATER-SURFACE AND VELOCITY PROFILES

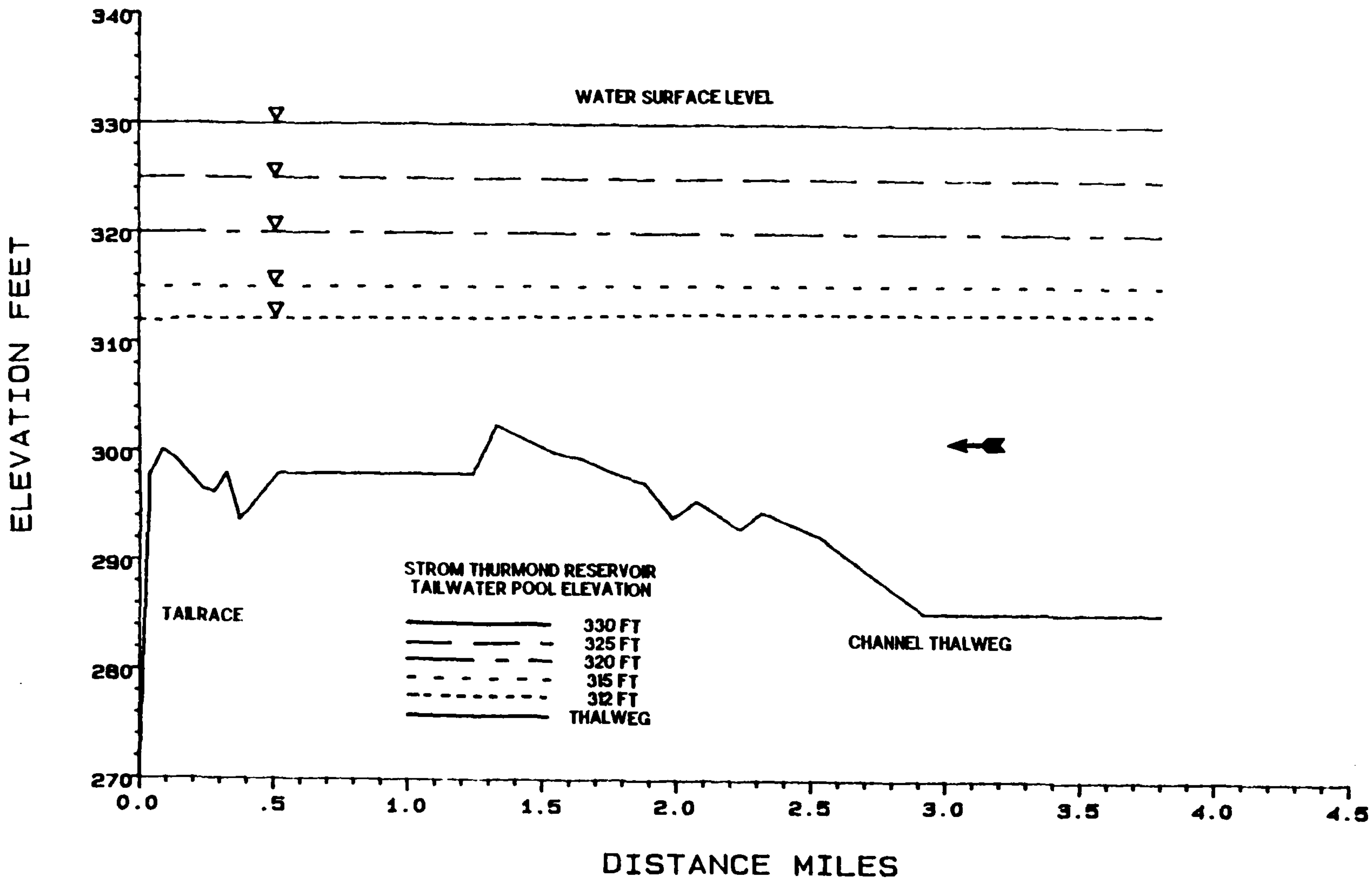


Figure B1. Water-surface profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 298 ft (n = 0.02)

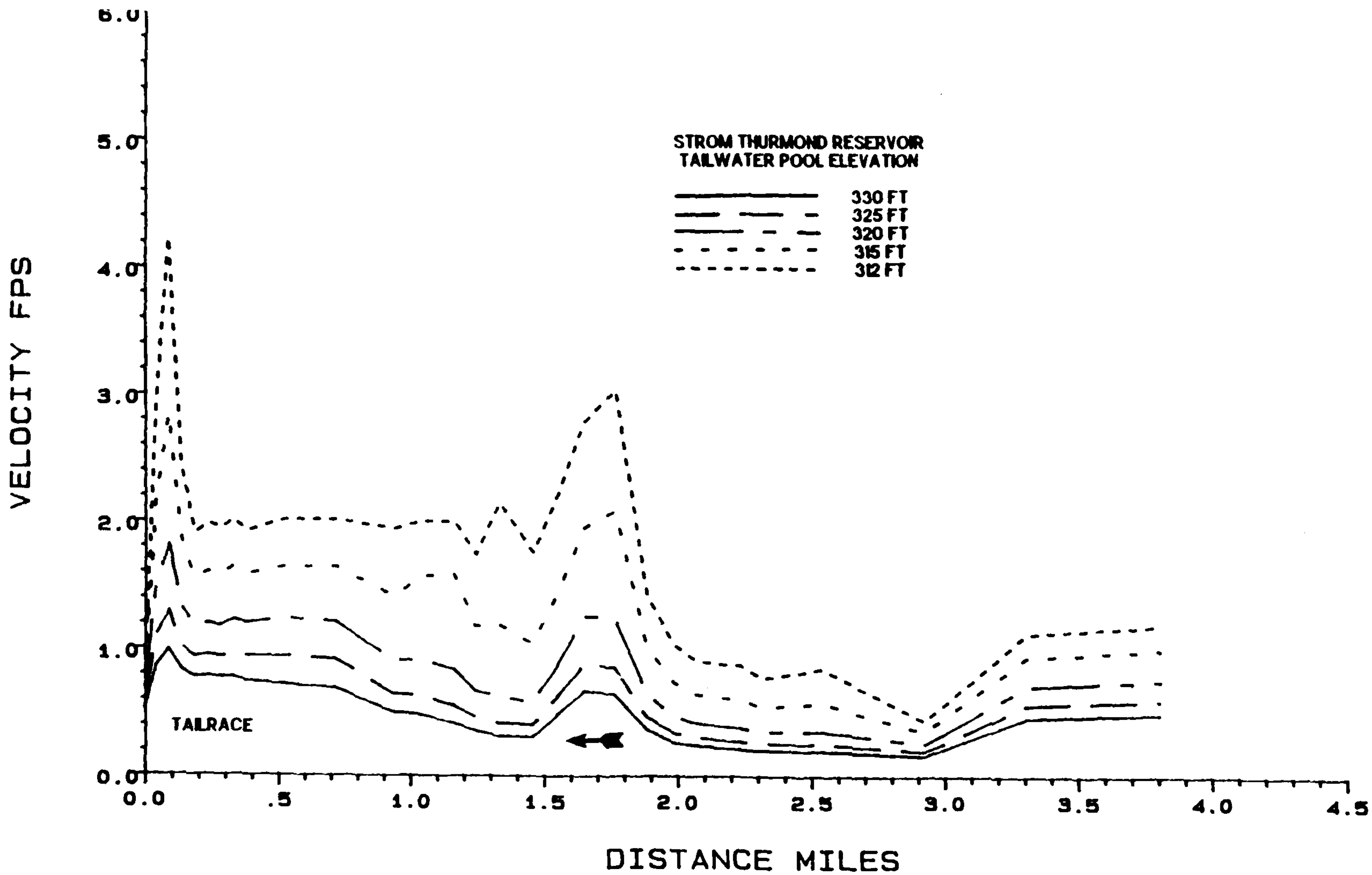


Figure B2. Velocity profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 298 ft (n = 0.02)

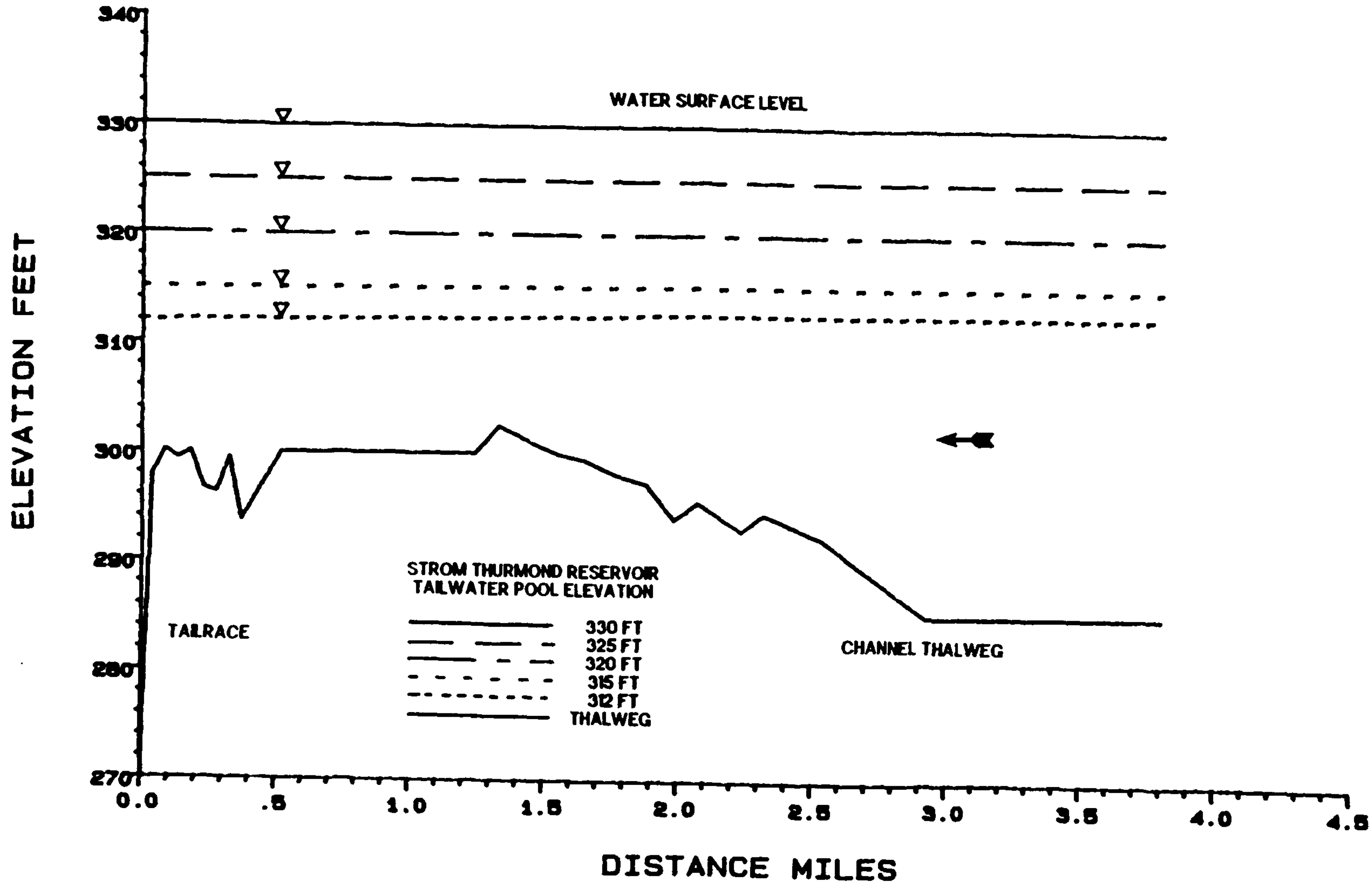


Figure B3. Water-surface profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 300 ft (n = 0.02)

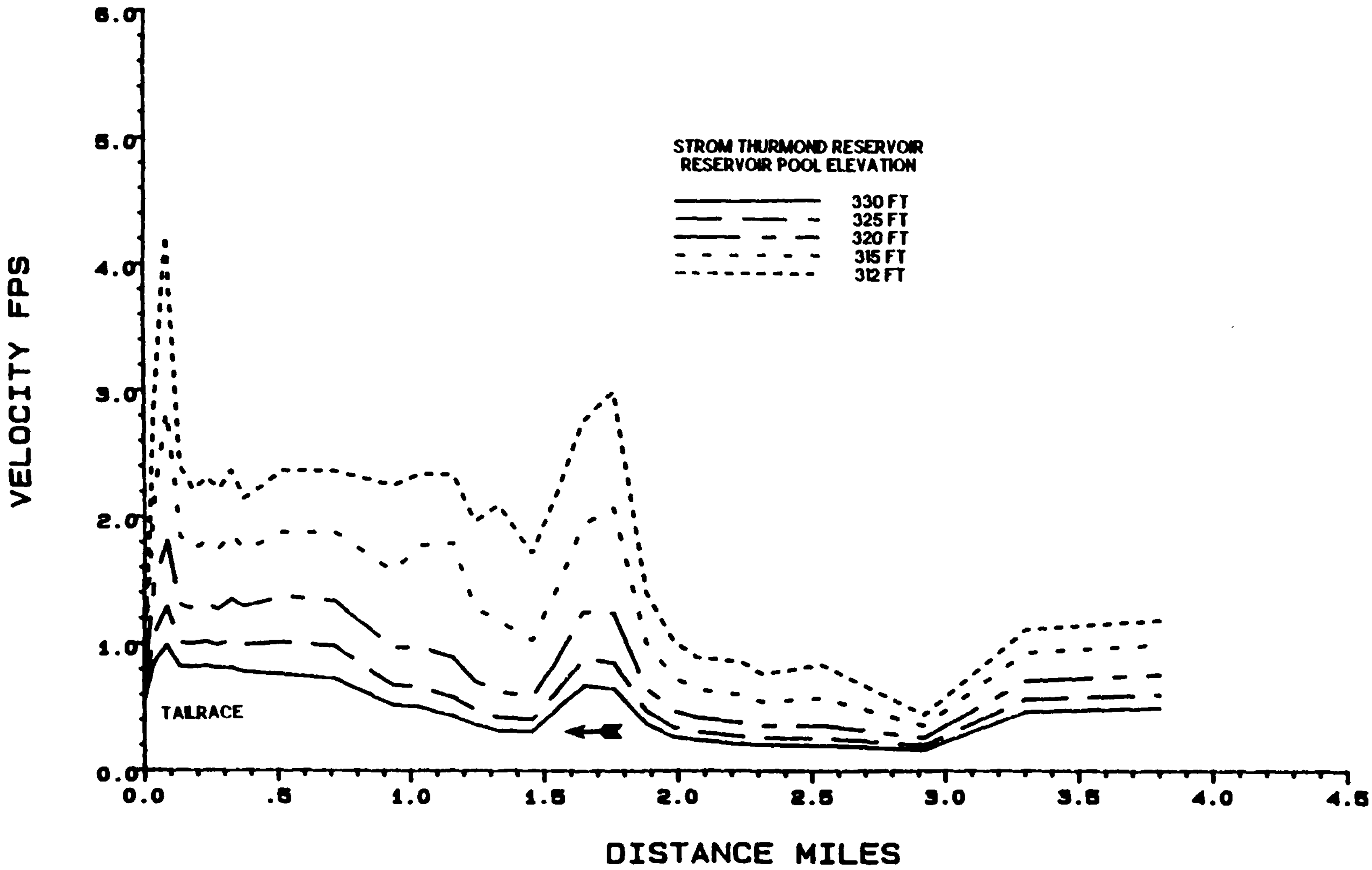


Figure B4. Velocity profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 300 ft (n = 0.02)

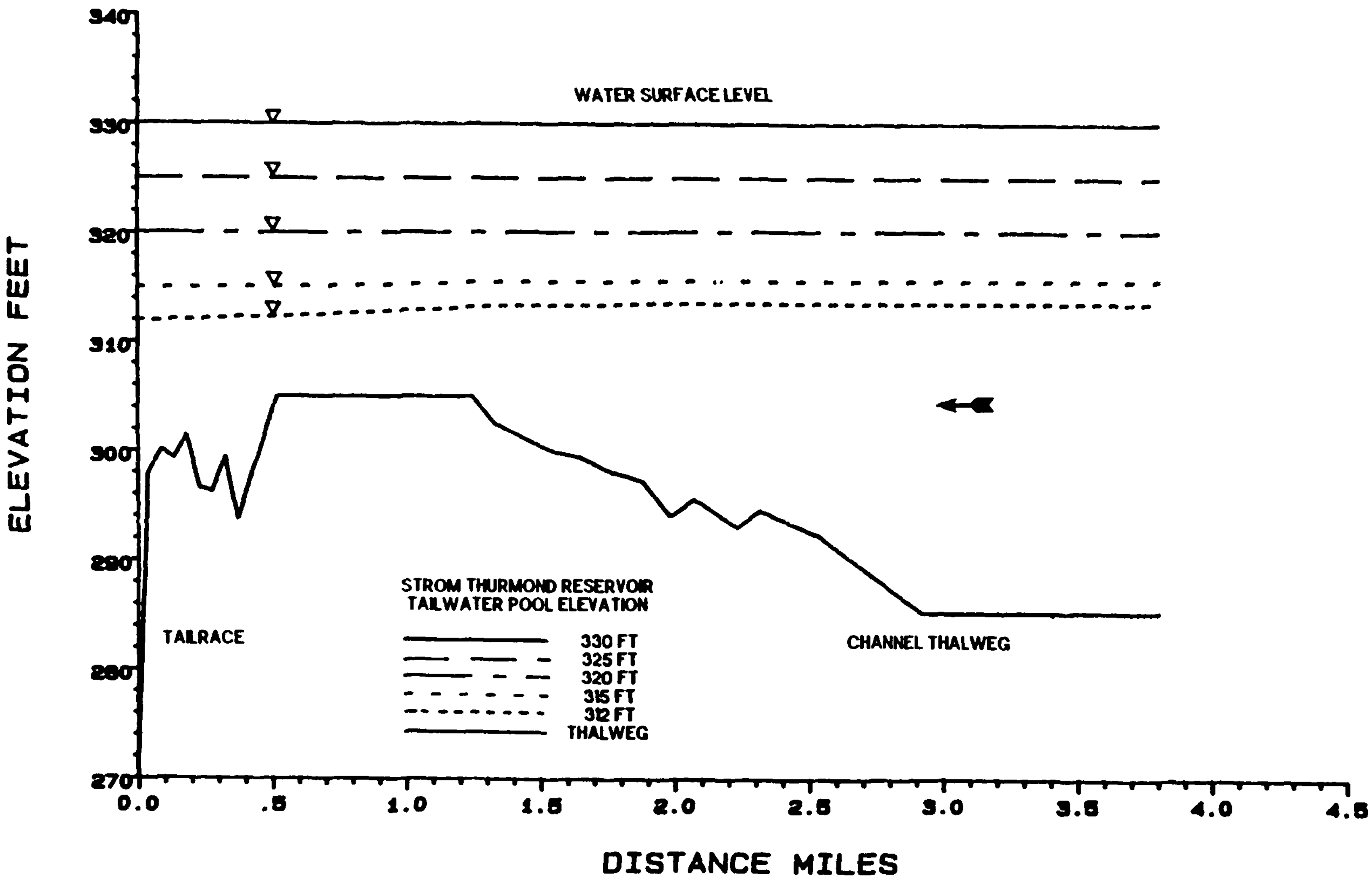


Figure B5. Water-surface profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 305 ft (n = 0.02)

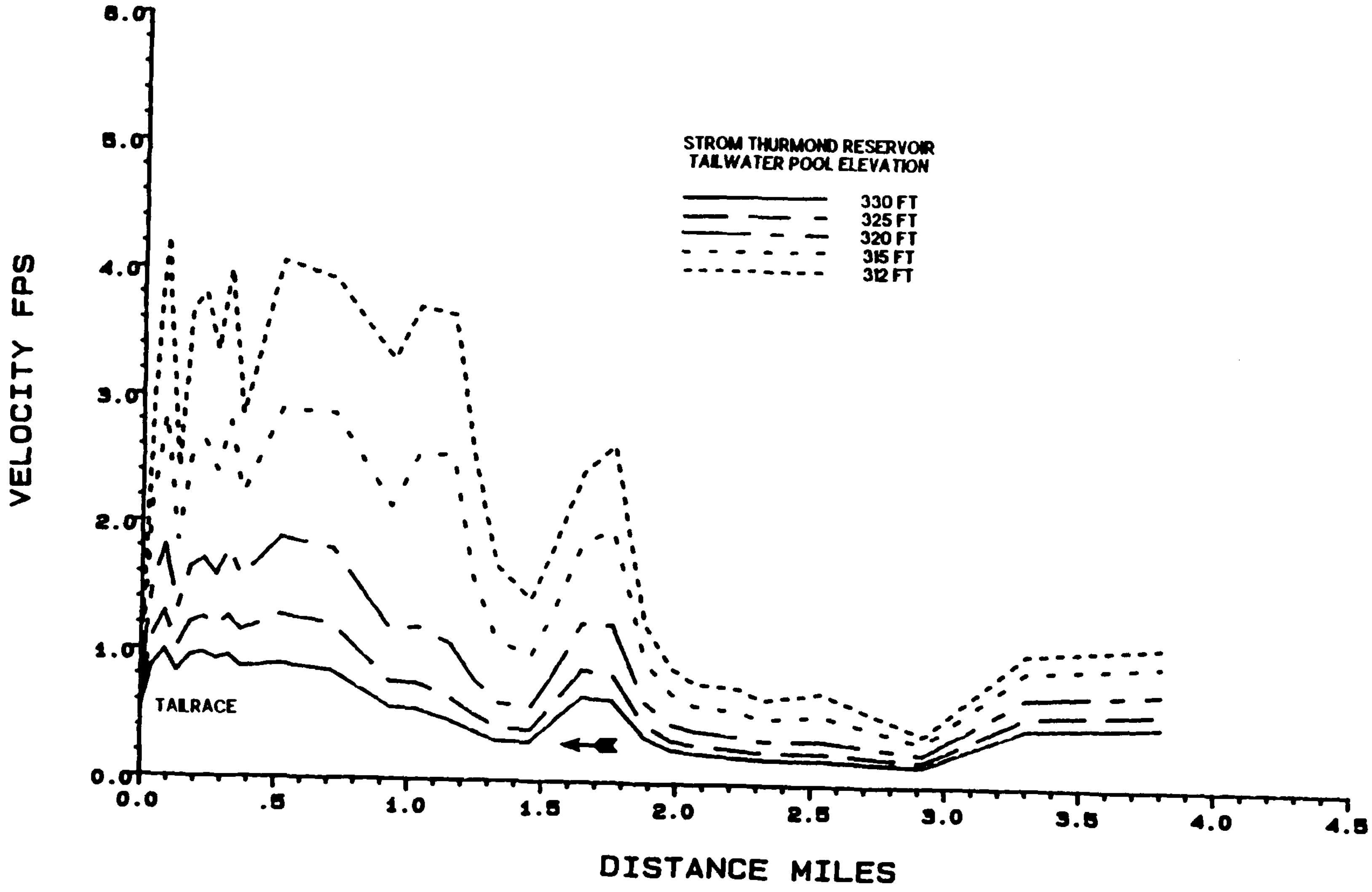


Figure B6. Velocity profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 305 ft (n = 0.02)

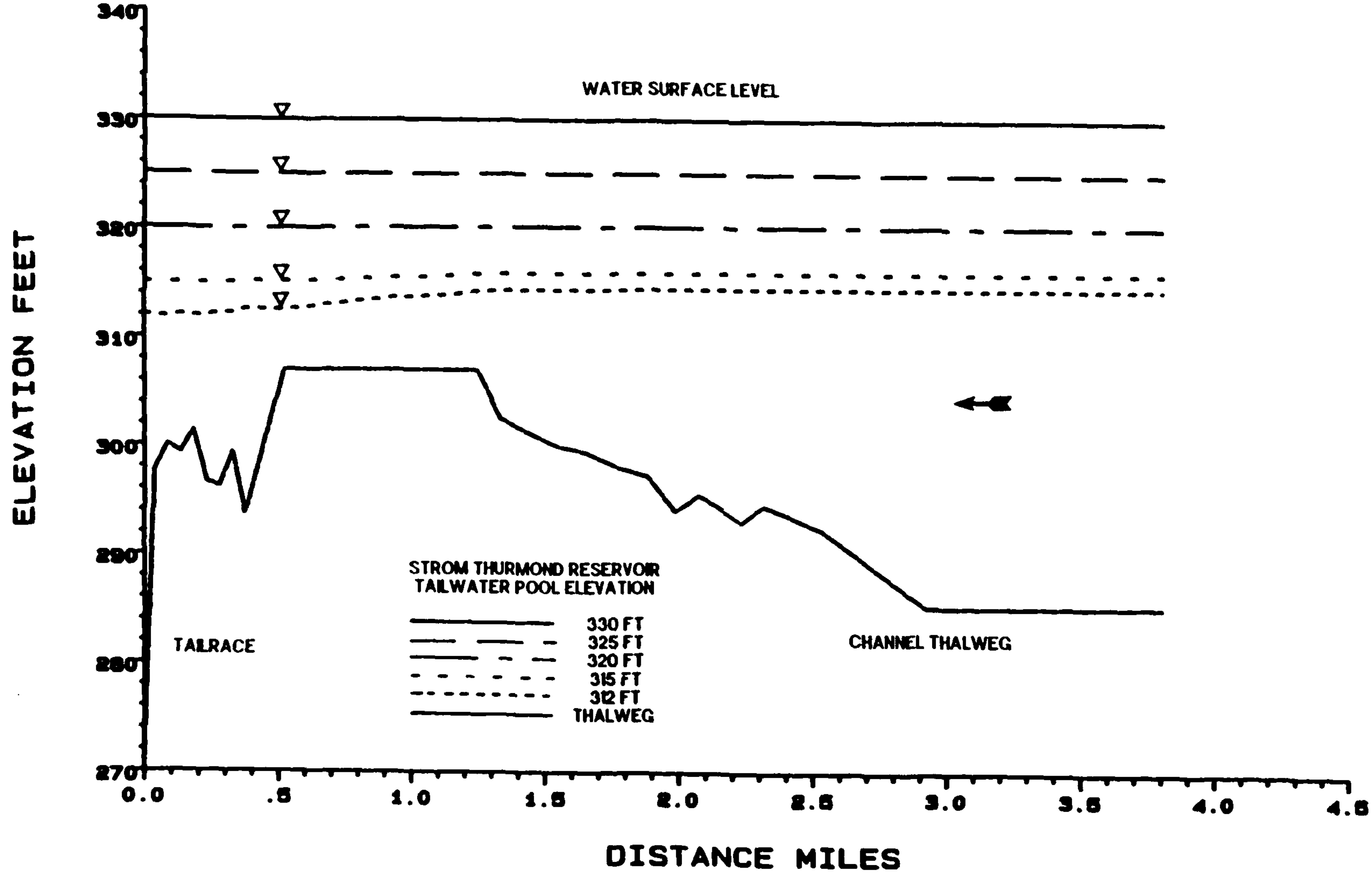


Figure B7. Water-surface profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 307 ft (n = 0.02)

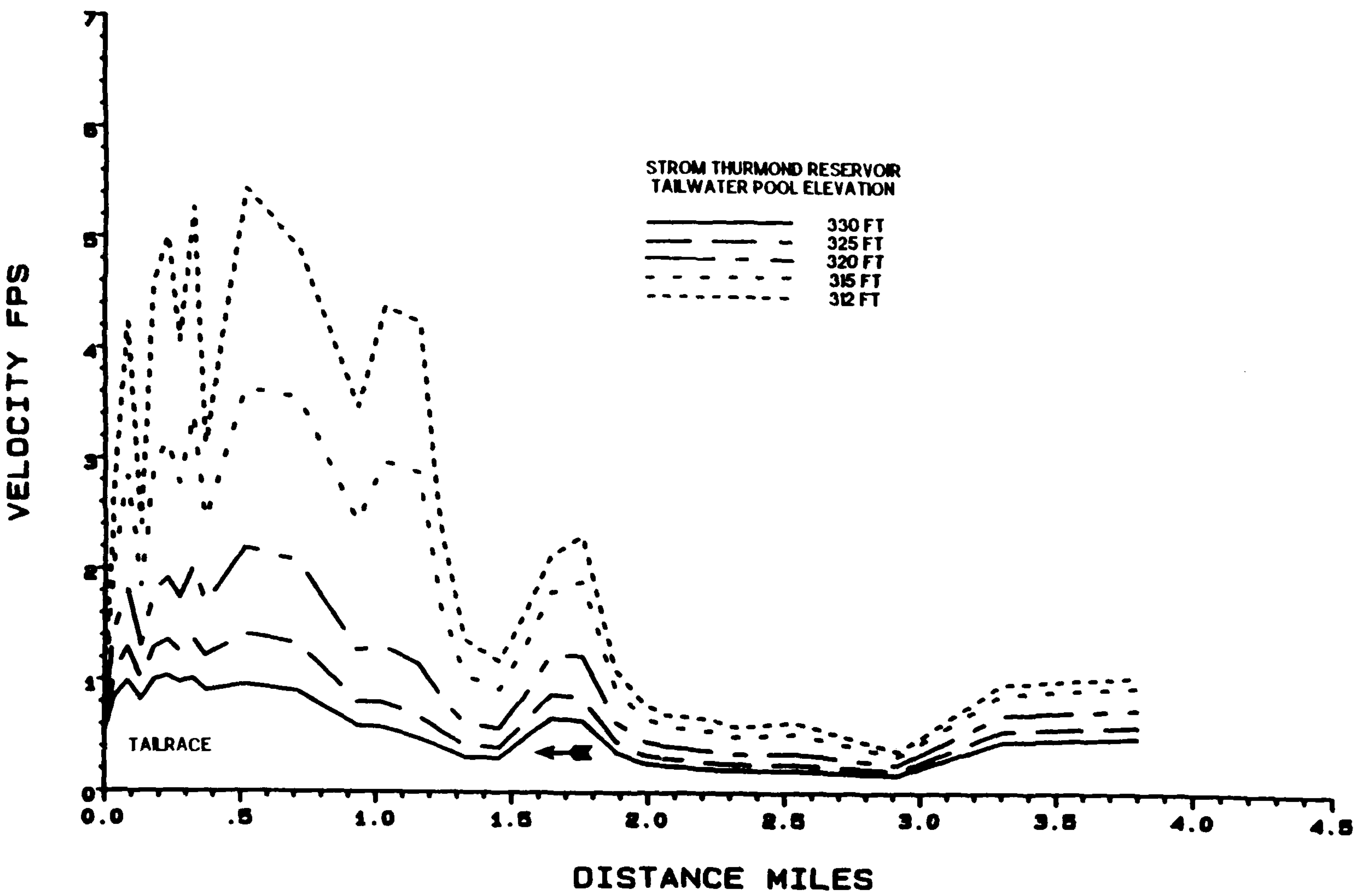


Figure B8. Velocity profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 307 ft (n = 0.02)

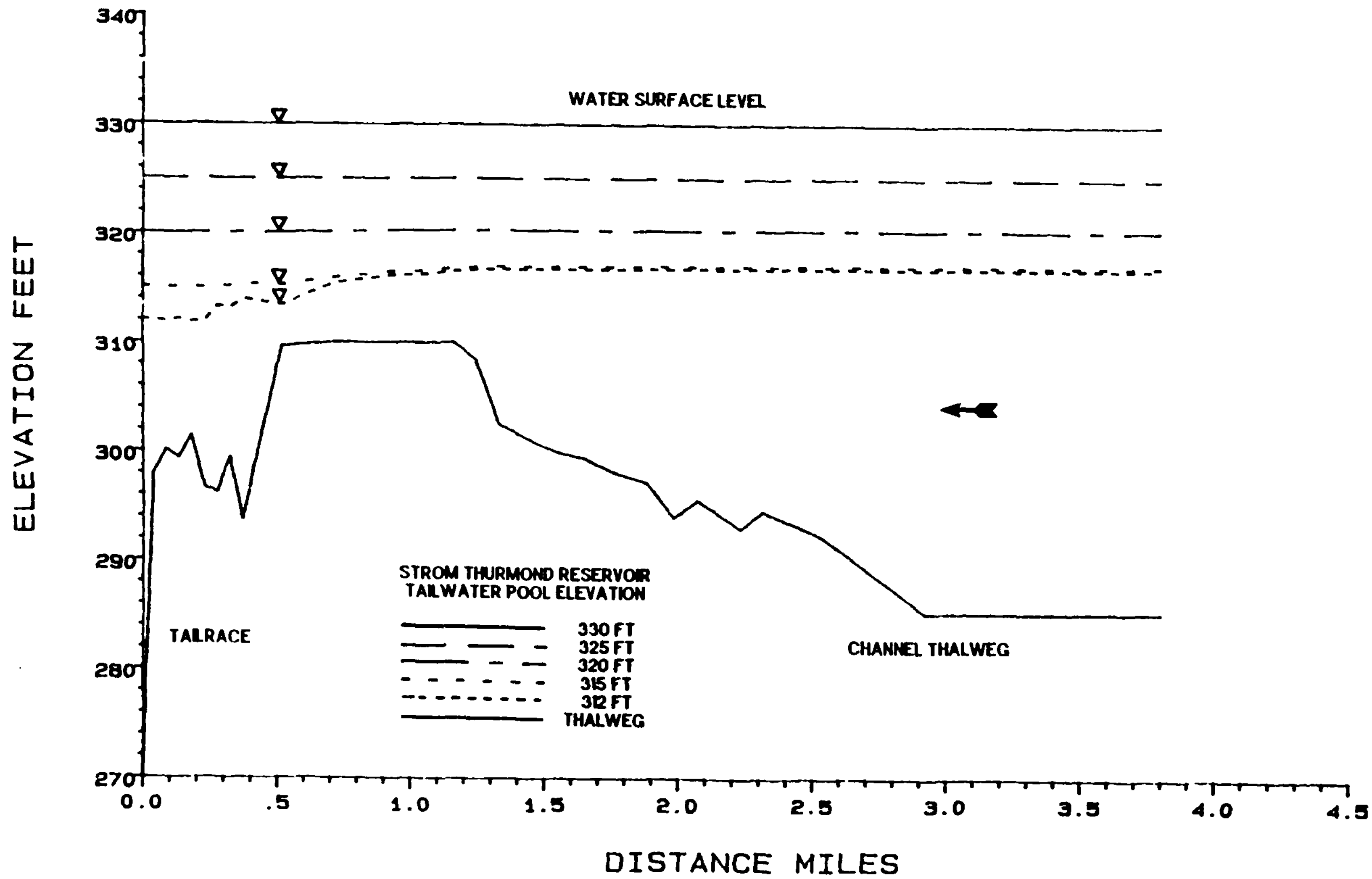
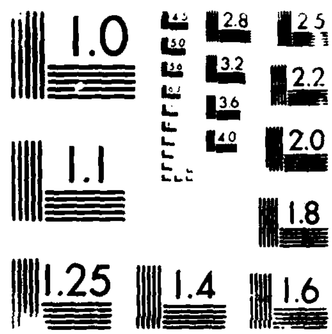


Figure B9. Water-surface profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 310 ft (n = 0.02)

AD-A210 184 HYDRAULIC ANALYSES OF J STROM THURMOND RESERVOIR
HEADWATERS(U) ARMY ENGINEER WATERWAYS EXPERIMENT
STATION VICKSBURG MS HYDRAULICS LAB M L SCHNEIDER
UNCLASSIFIED JUN 89 WES/MP/HL-89-2 F/G 13/2 NL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1.6

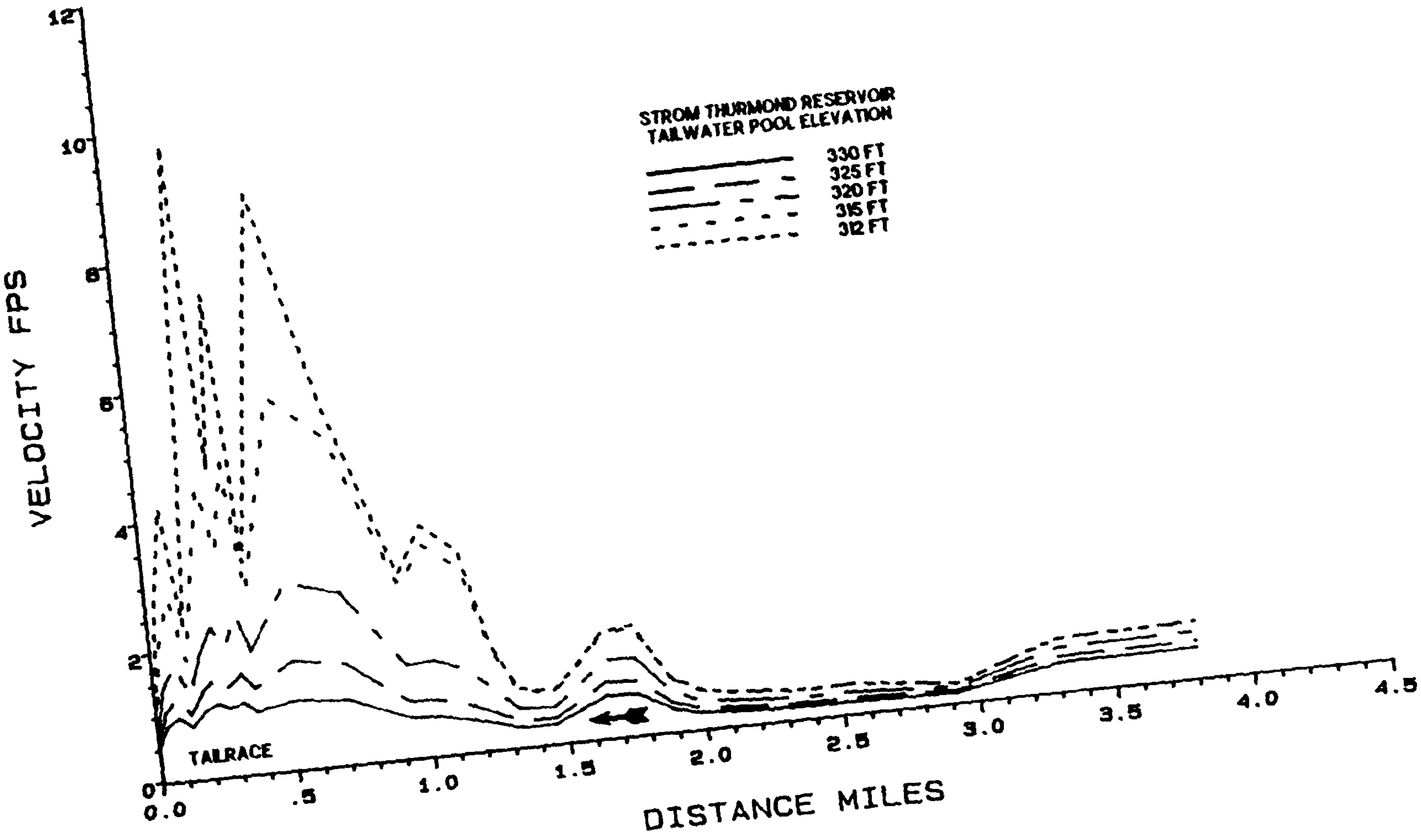

Figure B10. Velocity profiles for Strom Thurmond Reservoir pumpback Q = 24,800 cfs, excavation 310 ft (n = 0.02)

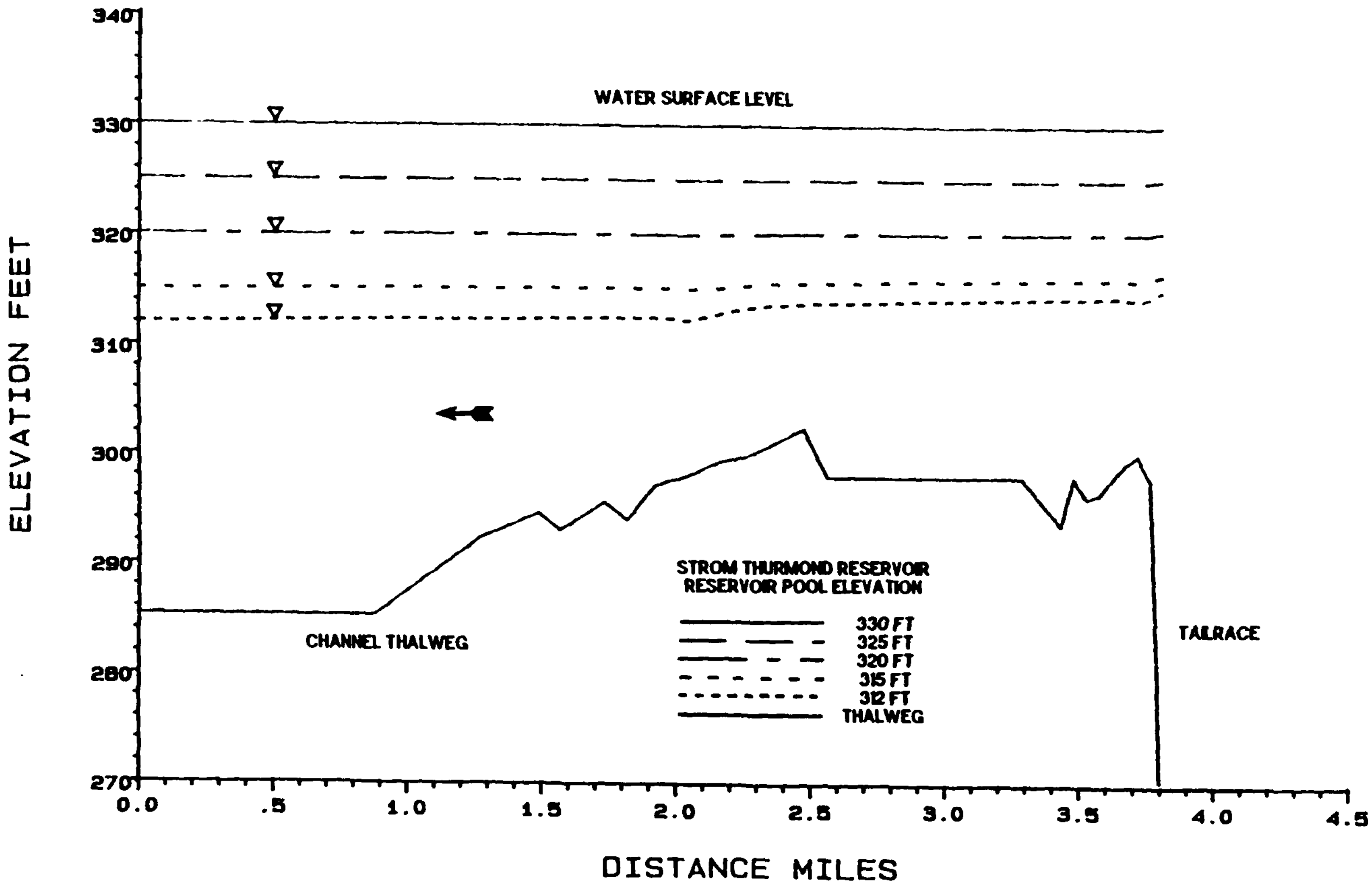

Figure B11. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 298 ft (n = 0.02)

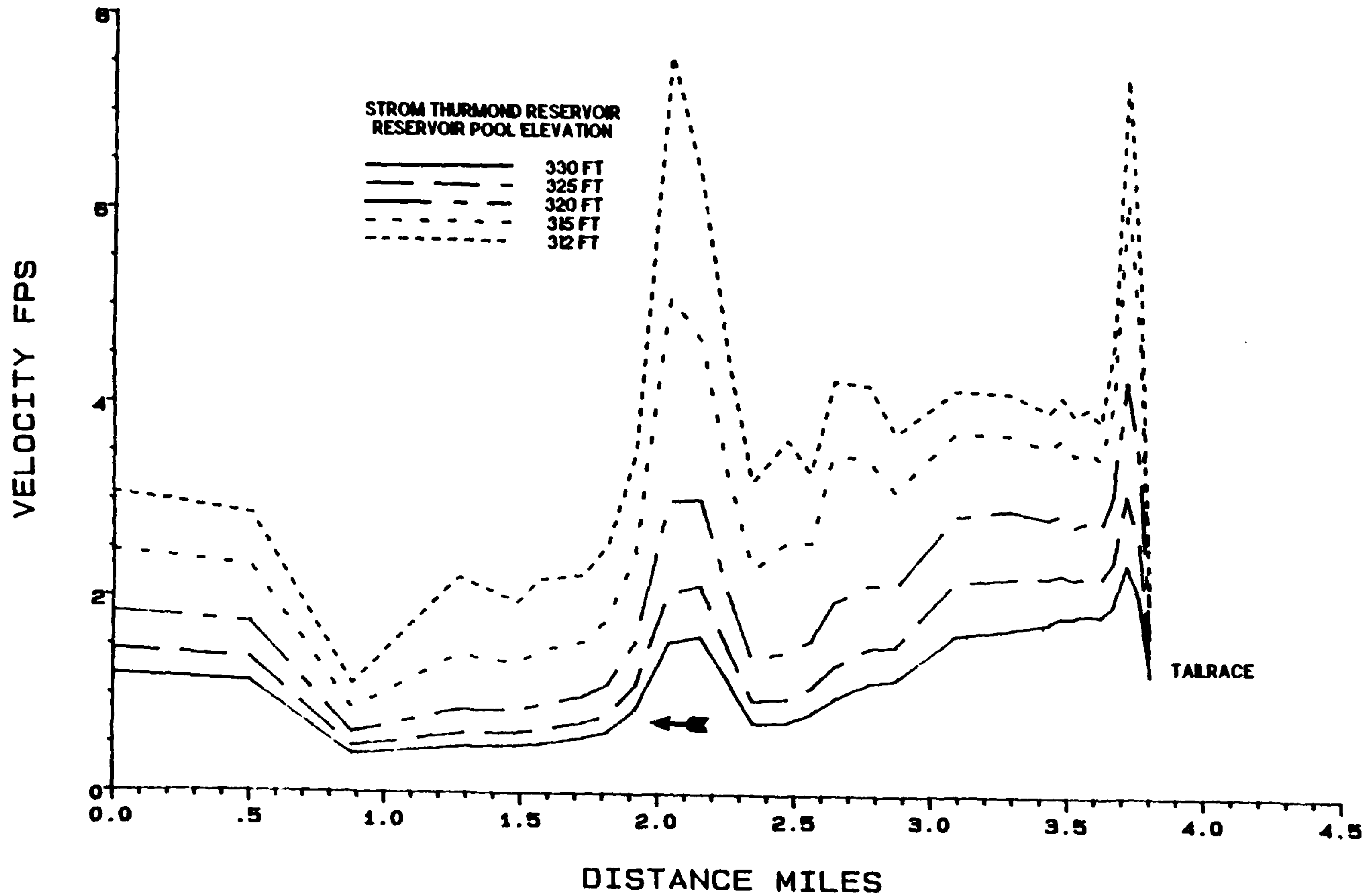

Figure B12. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 298 ft (n = 0.02)

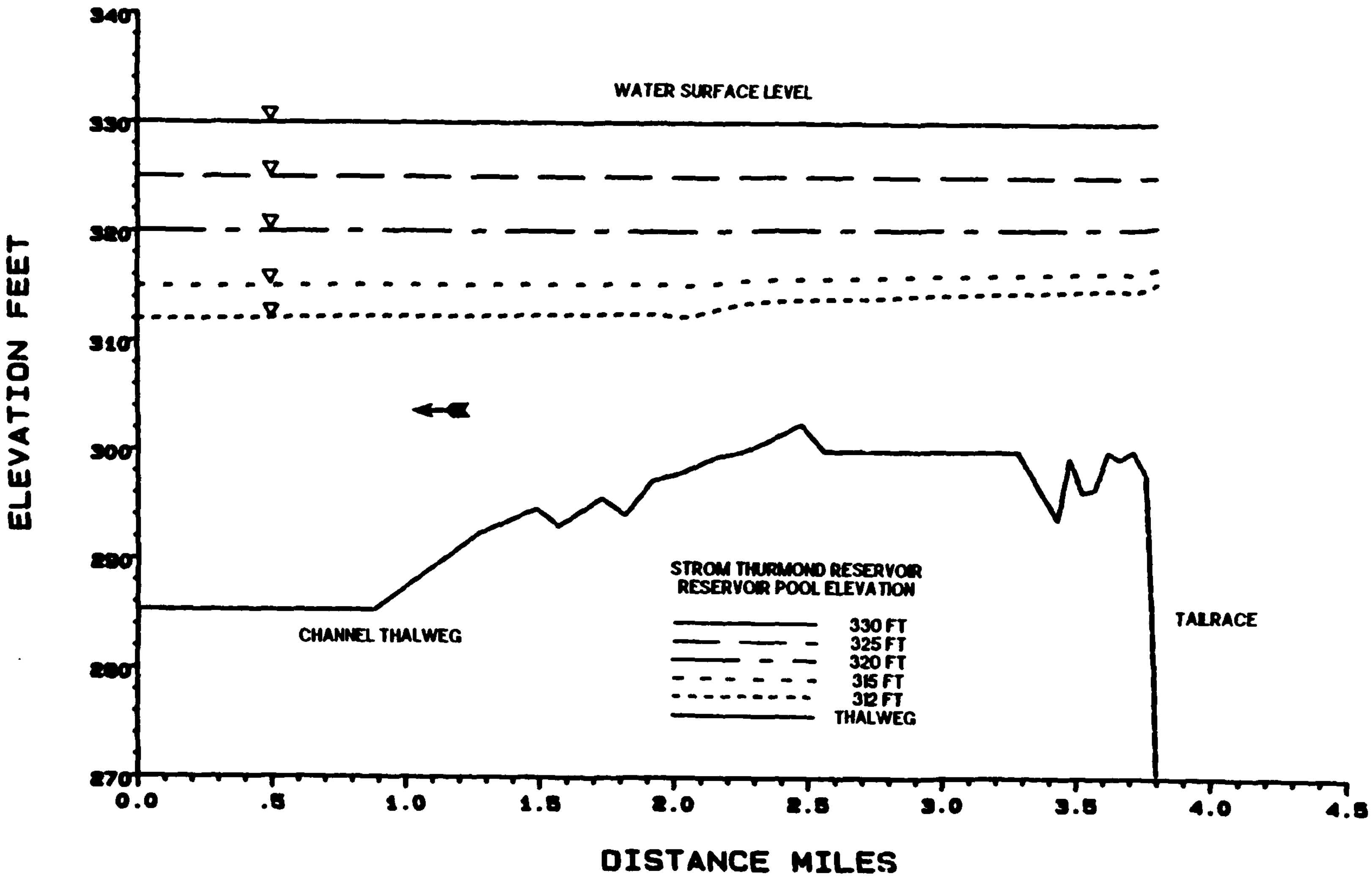

Figure B13. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 300 ft (n = 0.02)

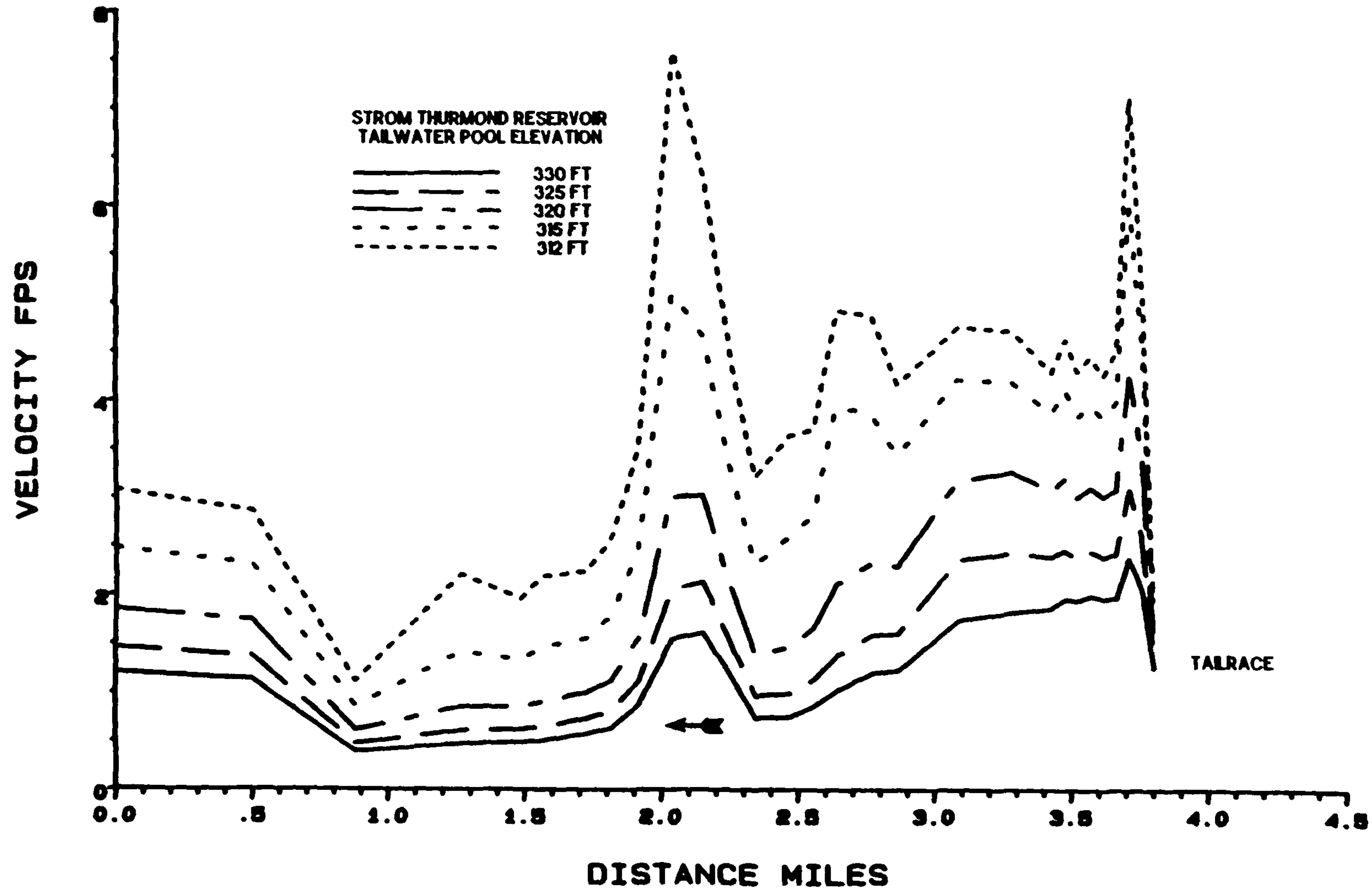

Figure B14. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 300 ft (n = 0.02)

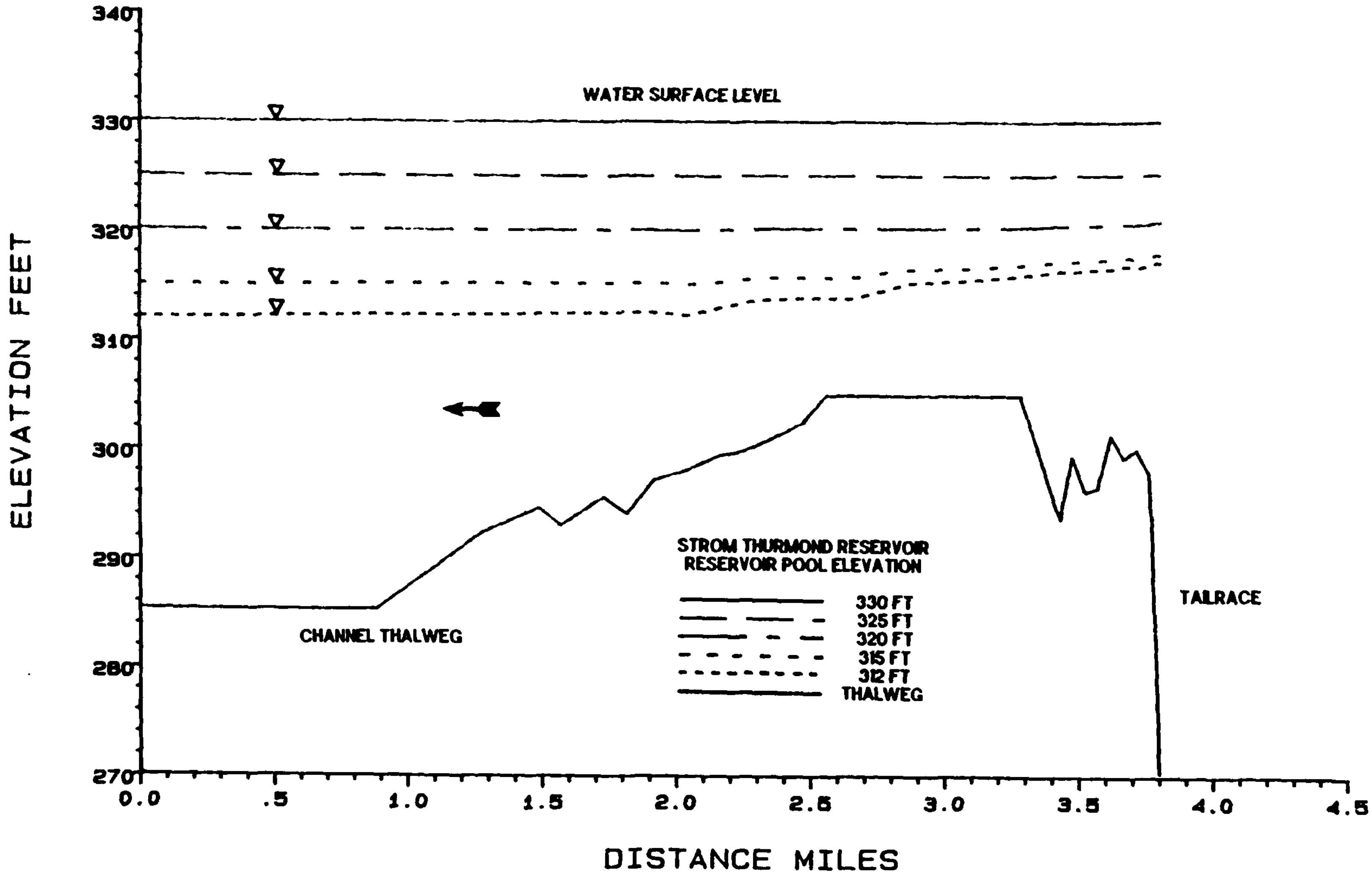

Figure B15. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 305 ft (n = 0.02)

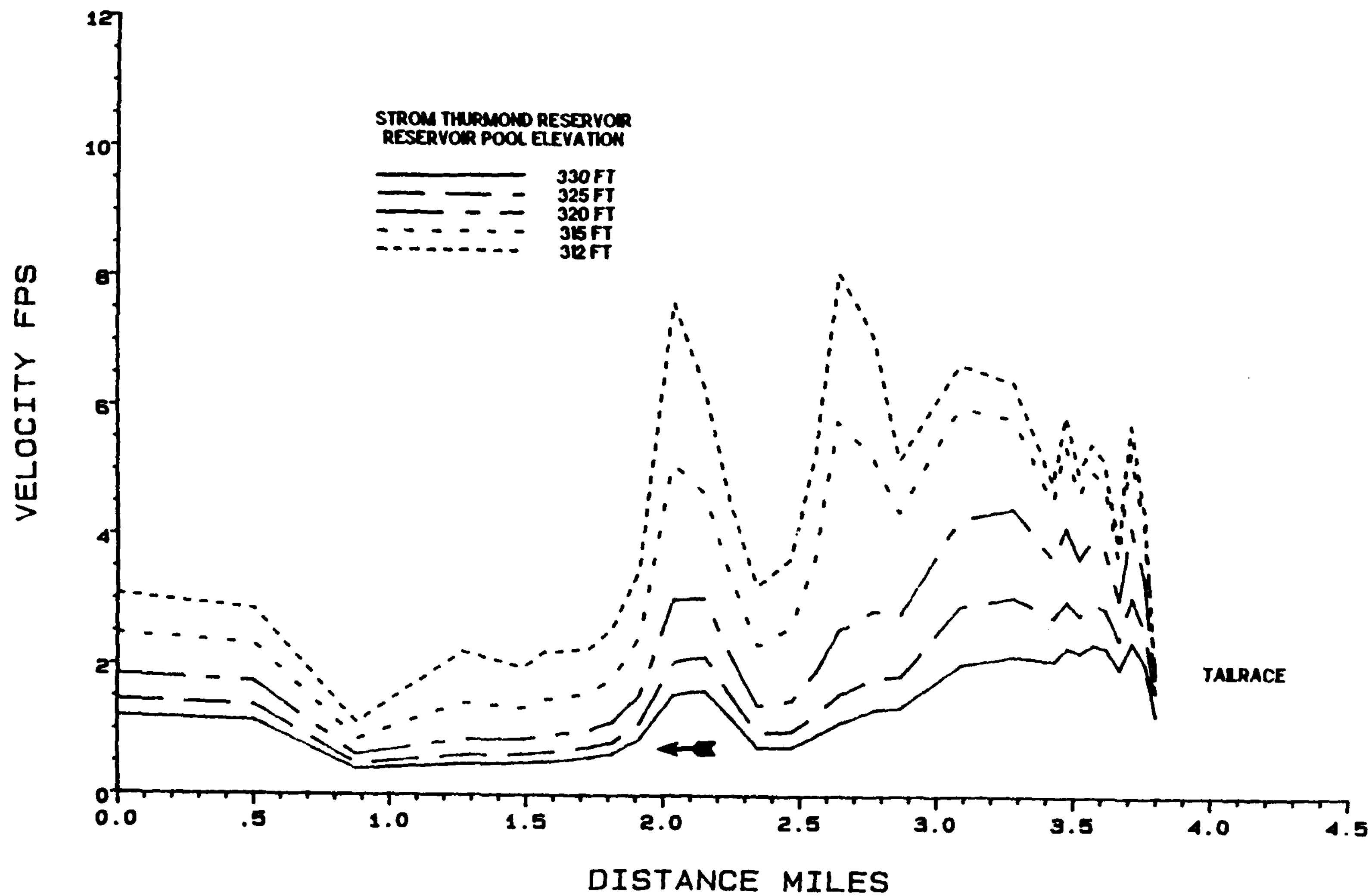

Figure B16. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 305 ft (n = 0.02)

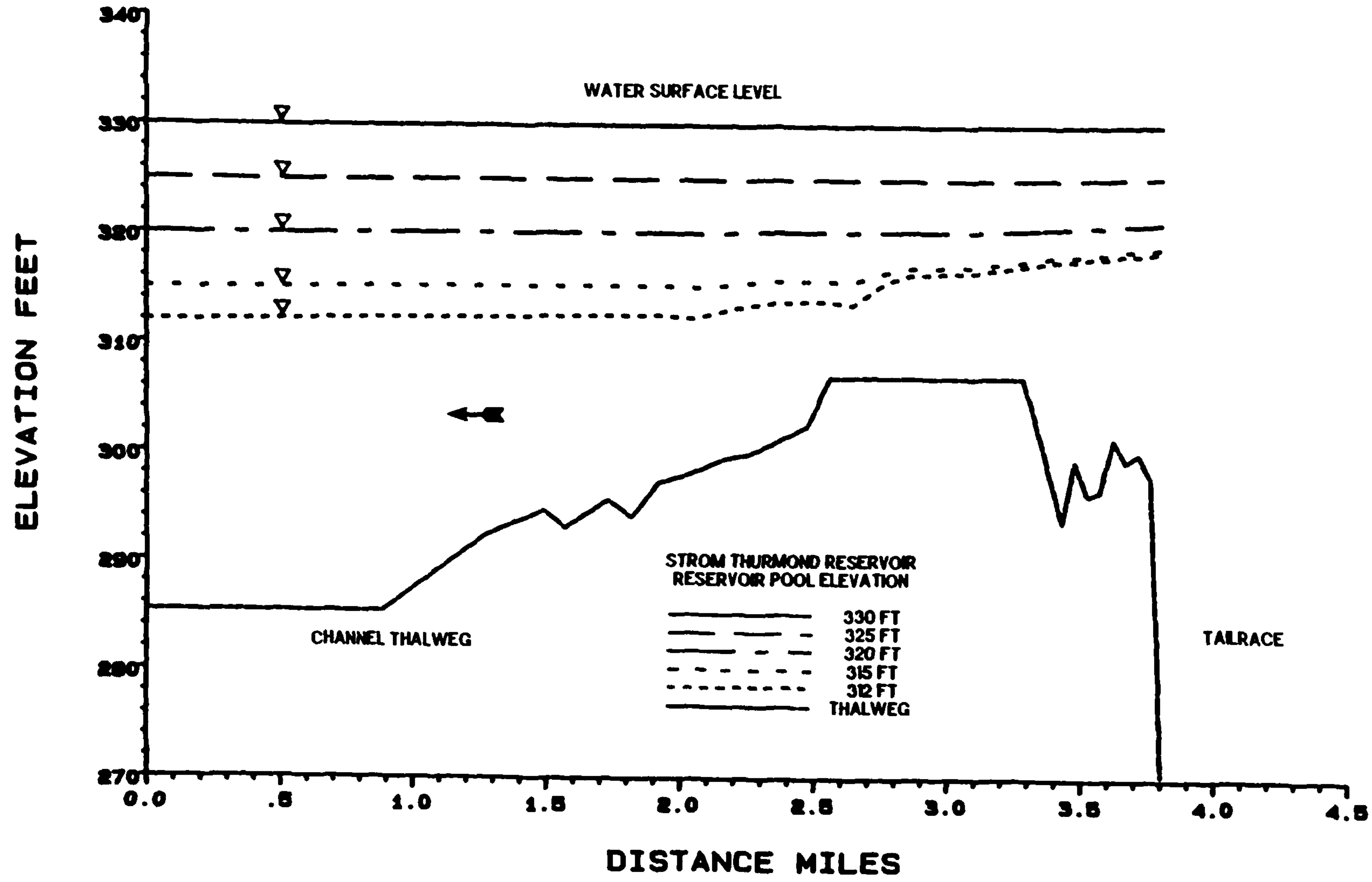

Figure B17. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 307 ft (n = 0.02)

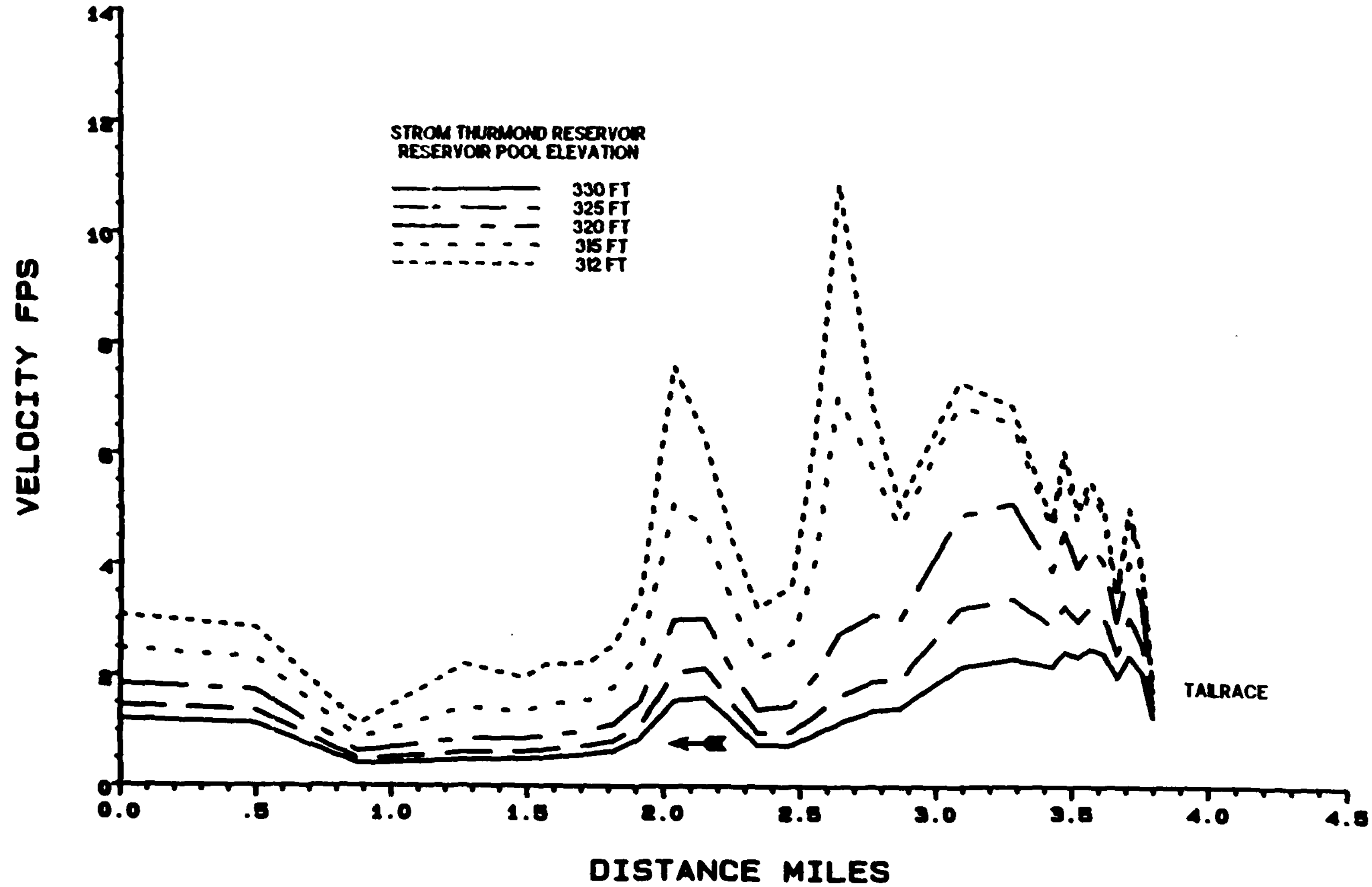

Figure B18. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 307 ft (n = 0.02)

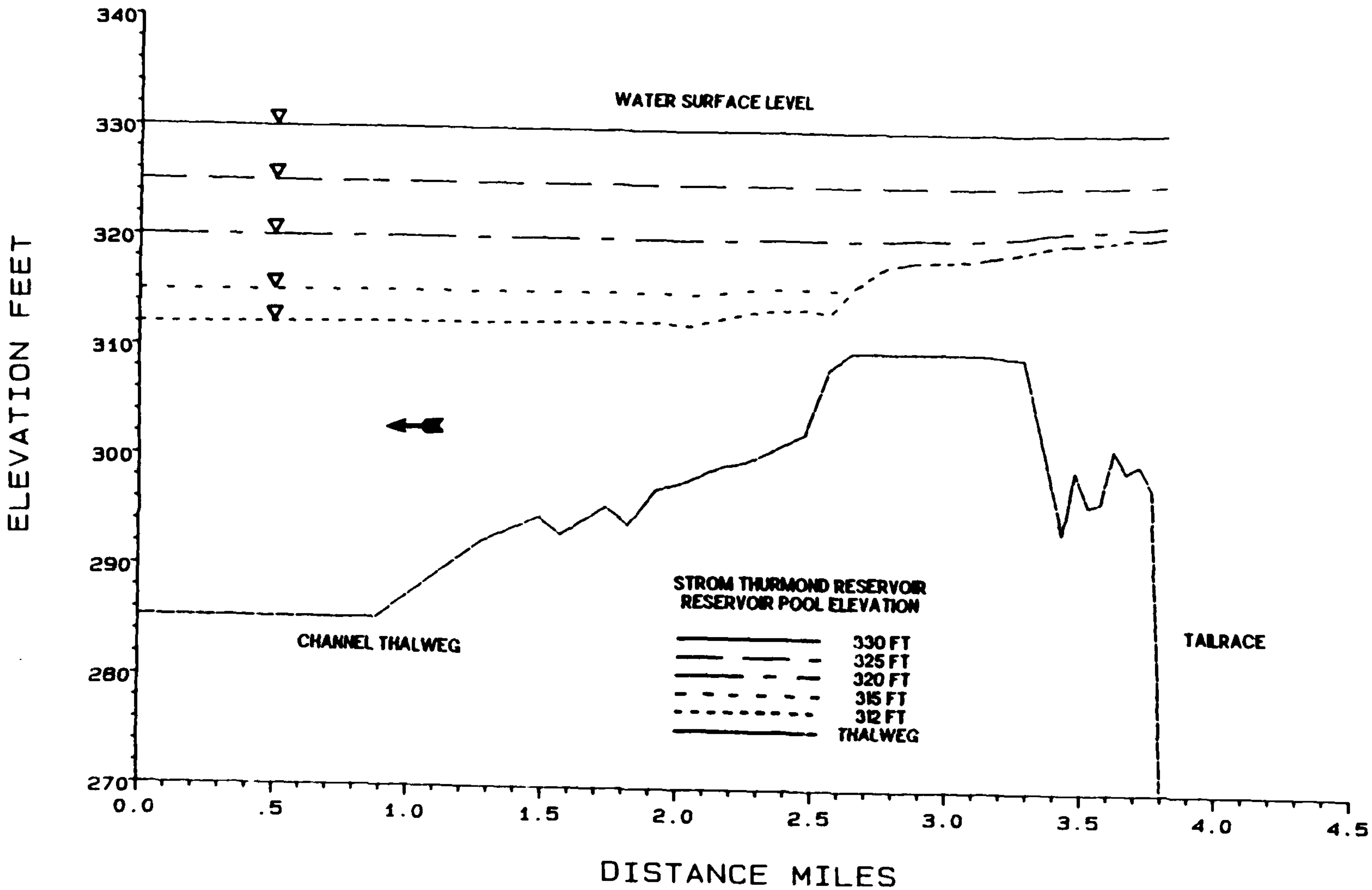

Figure B19. Water-surface profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 310 ft (n = 0.02)

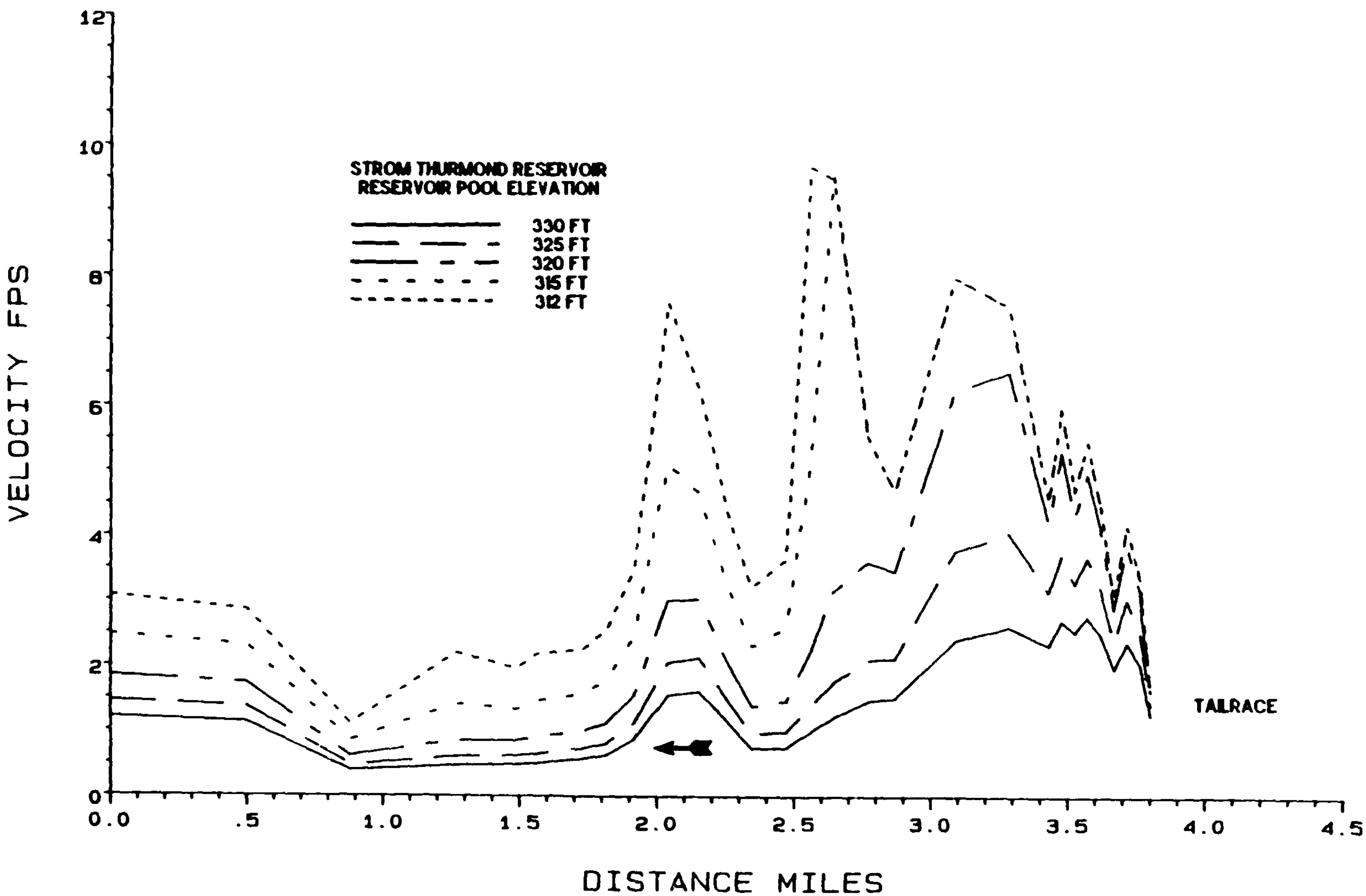

Figure B20. Velocity profiles for Strom Thurmond Reservoir generation Q = 60,000 cfs, excavation 310 ft (n = 0.02)